

HiRel: Hybrid Automated Reliability Predictor (HARP) Integrated Reliability Tool System (Version 7.0)

HARP Output (HARPO) Graphics Display User's Guide

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The tool system was designed at the outset to be compatible with most computing platforms and operating systems, and some programs have been beta tested within the aerospace community for over 8 years. Many examples of HiRel's use have been reported in the literature and at the HARP Workshop conducted at Duke University, July 10–11, 1990.

The wide range of applications of interest has caused HiRel to evolve into a family of independent programs that communicate with each other through ASCII files that each program generates. In this sense, HiRel offers a toolbox of integrated programs that can be executed to customize the user's application.

The modeling engines are comprised of four self-contained executable software programs: the original HARP program (described in vols. 1 and 2 of this TP), the Monte Carlo integrated HARP (MCI-HARP) (ref. 3), Phased-Mission HARP (PM-HARP) (ref. 4), and the X Window system HARP (XHARP) (ref. 5). In conjunction with the engine suite are two input/output interactive graphical user-interface programs that provide a workstation environment for HiRel. These programs are called the Graphics Oriented (GO) program (vol. 3 of this TP) and the HARP Output (HARPO) program. The base components of HiRel (GO, HARP, MCI-HARP, and HARPO) are available through NASA's software distribution facility.¹ The X-HARP engine² is available from the university where it was developed. PM-HARP³ can be obtained from the Boeing Commercial Airplane Group.

HARPO was designed to be more than a graphics display program for HARP. It was designed to provide a means for analyzing huge amounts of reliability data to enable the user to make trade-offs between design alternatives within a particular system architecture and to compare different system architectures. Although this program can be used without an indepth knowledge of the HARP capability, correct interpretation of the graphical data requires that knowledge. Thus, the user should read the *HARP Introduction and User's Guide*, volume 1 of this Technical Paper.

HARPO is designed to be executed from an interactive graphics workstation. It is written in ANSI FORTRAN 77 and complies with the Graphical Kernel System (GKS) standard (ref. 6). The program is portable between DEC VAXstation II workstations executing VMS, Sun Microsystems workstations executing UNIX, and IBM-compatible personal computers (PC's) executing DOS. HARPO is compatible with data files as formatted by HARP version 7.0. HARPO generates the following two types of interactive graphical displays: (1) probability of failure versus time on a log-linear scale and (2) probability of failure versus failure rate at one specific time on a log-log scale. The data displayed on these graphs represent numerous types of state probabilities, unreliability, and bounds on unreliability.

This volume introduces the user to the HARPO capabilities. Chapter 2 presents examples and screen displays representative of HARPO applications. Chapter 3 discusses workstation specifics pertaining to the HARPO program. File naming conventions, file data interpretations, and program limitations are also presented. Chapter 4 covers display directives that allow the user to display and manipulate data. Chapter 5 presents the workstation requirements necessary for the proper hardware and software capabilities for HARPO execution and display and concludes with installation information. In addition, appendix A contains a sample HARPO session on a Sun workstation that demonstrates the power of the HARPO interactive graphics capability, and appendix B gives a listing of error messages. A glossary of the main abbreviations in this paper is also given.

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²Clemson University, Dept. of Computer Science, Clemson, SC 29734 (Robert Geist).

³The Boeing Commercial Airplane Group, Seattle, WA 98124 (Tilak Sharma).

Chapter 1

Introduction

The Hybrid Automated Reliability Predictor (ref. 1) (HARP) Output (HARPO) graphical display program allows the user to process and visually represent output from the HARP program. The execution of *harpeng*, one of the HARP programs, creates two files that contain data suitable for graphical plotting. These files are called the PT (plot) and the RS (results) data files. The PT file contains only the unreliability values versus the mission times in a two-column format where each row represents an ordered X-Y pair. This format is easily readable by graphical and spreadsheet programs for quick plots. HARPO uses only the RS file, which includes the plot data. The HARPO program accesses the data through interactive prompts and menus in a graphical display environment. HARPO and HARP are members of the HARP integrated Reliability (HiRel) tool system (refs. 1 and 2), which is described in volume 1 of this Technical Paper. Figure 1 shows the basic HiRel software and the typical flow of the programs.

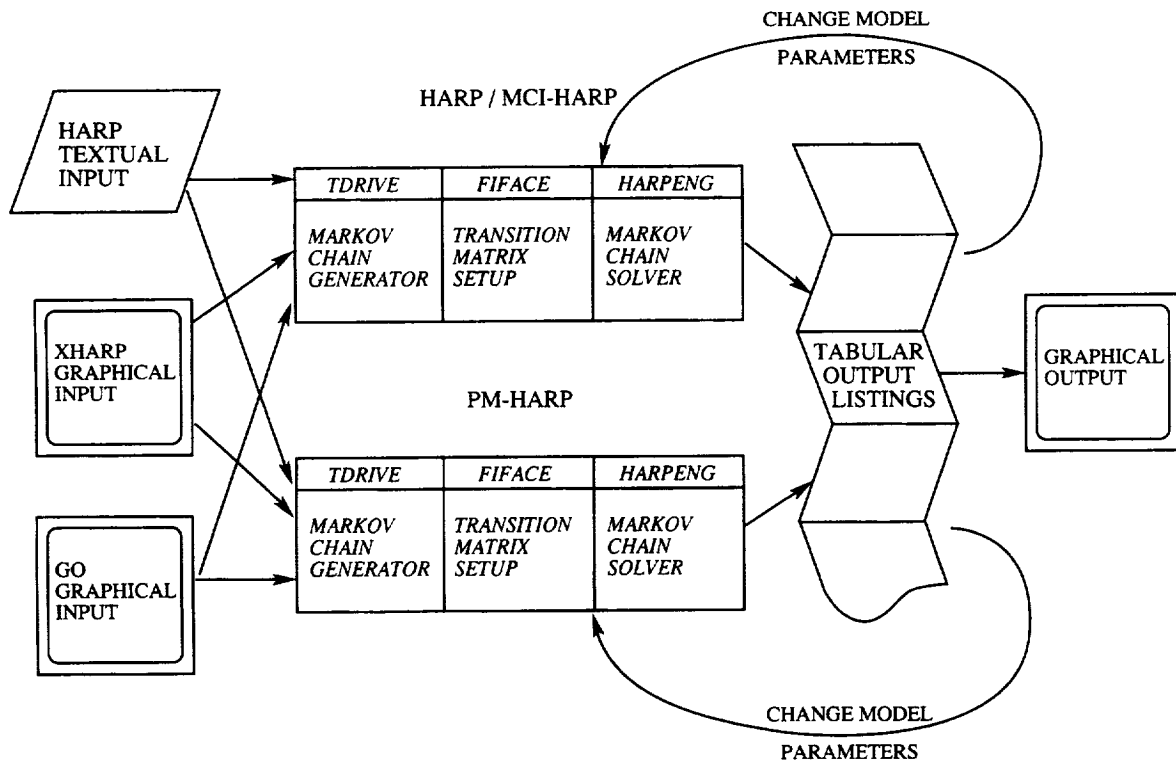


Figure 1. HiRel flow relationships.

HiRel offers a toolbox of integrated reliability/availability programs that can be used to customize the user's application in a workstation or nonworkstation environment. HiRel consists of interactive graphical input/output programs and four reliability/availability modeling engines that provide analytical and simulative solutions to a wide host of highly reliable fault-tolerant system architectures as well as many electronic systems. Three of HiRel's programs were developed by researchers at Duke University and NASA Langley Research Center.

Chapter 2

Overview of HARPO Capabilities

This chapter presents representative applications for the HARPO program, which can be executed independently from the other HiRel programs once the plot data are available. Aside from the flexibility of presenting various types of data, HARPO allows the user to interact with the graphical data in a real-time manner. The dynamics of real-time data manipulation can be best appreciated with hands-on usage. In a workstation environment, HARPO presents the design engineer with a powerful evaluation tool.

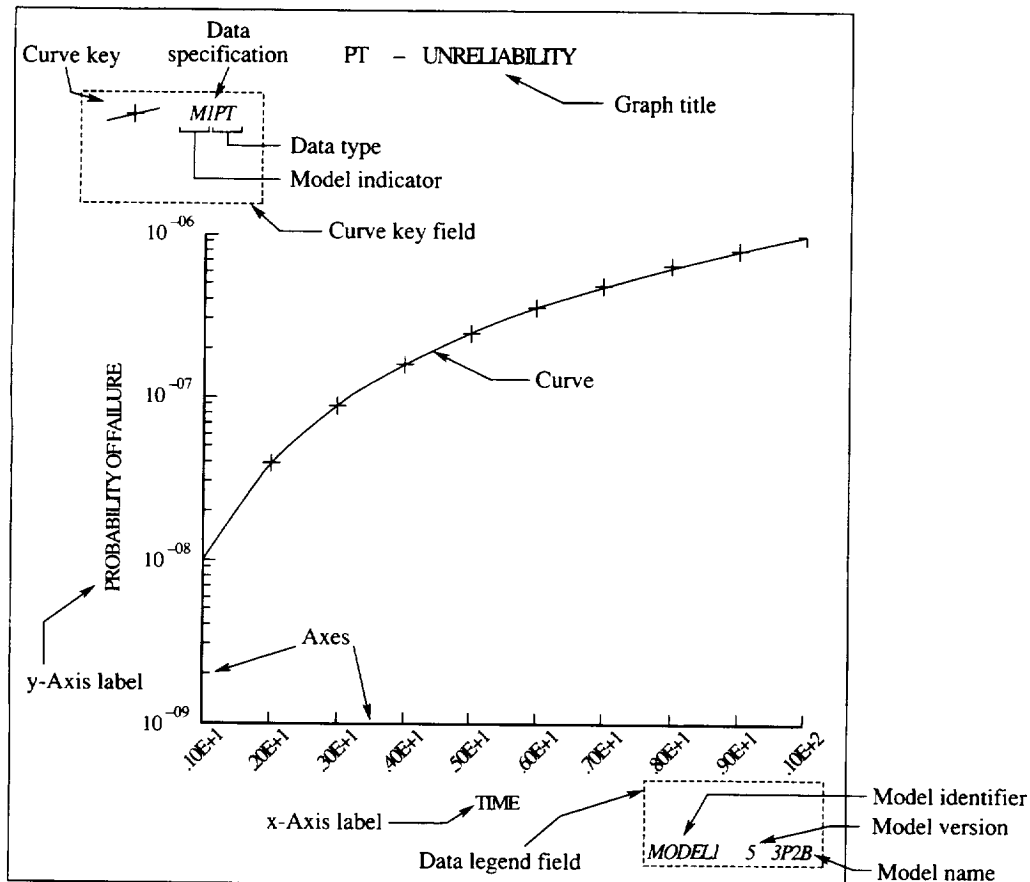


Figure 2. Annotated HARPO graph.

Figure 2 shows the HARPO screen with position of the data legend and curve key fields, the various titles and labels, and the axes. The screen image also shows the unreliability (probability of system failure) for the model identified as MODEL1, which is shown in the data legend (bottom right of screen). The data legend lists the active models where the top model listed is currently displayed. The character string 3P2B is the file name, and the number 5 in the middle column is the file version number. Thus, MODEL1 5 3P2B means that the file 3P2B.RS5 contains MODEL1. The version number 5 was concatenated to the characters RS to form the file extension RS1. The file name is typically associated with the model's name, and the file version number is the version of that model. The characters RS denote that this file is a HARP results file. The top of the screen shows the characters PT, which means

the plotted data from the results file 3P2B.RS5 are the same as that in the PT file. The user can only display the *harpeng* generated data from the results file.

The character strings at the top left of the screen provide the key for the plotted graphs. On the computer screen, each graph is assigned a unique color and a unique symbol for identification on black and white hard copies. The strings M2, M3, and M4 correspond to the model identifications that are assigned sequentially according to data file activation/deactivation (bottom right of the screen). The PT string identifies the data type. The following sections give a brief description and a sample screen for representative applications for the HARPO program.

2.1. Unreliability Versus Mission Time

Figure 3 shows plot data from three versions of a model named EX29. The key strings from top to bottom, identify the following: (1) the model four-point data from file EX29.RS3, (2) the model three-point data from file EX29.RS2, and (3) the model two-point data from file EX29.RS1. A MODEL1 data file was deactivated before producing this graph. Model variation can be analyzed in this manner.

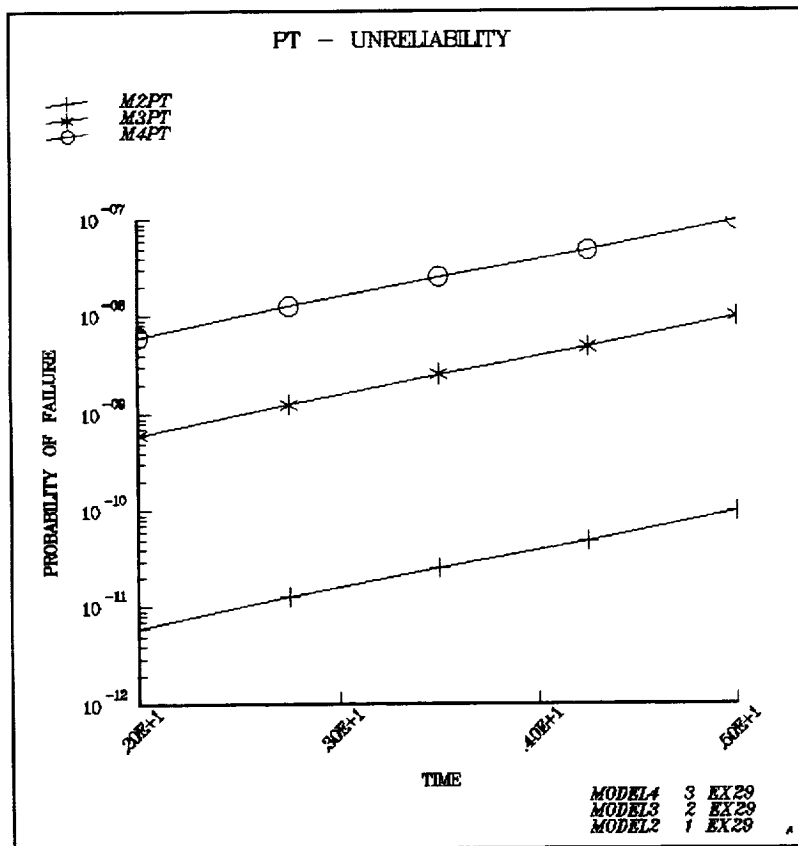


Figure 3. Unreliability versus mission time for three models.

2.2. Probability of Failure Bounds

Figure 4 shows two curves representing upper and lower simple bounds data for MODEL1 version 5 from file 3P2B.RS5. The top left strings identify the MODEL1 lower bound (M1BDLO) and upper bound (M1BDUP). The filename 3P2B represents a model with three processors and two bus

subsystems. This model and the interpretation of the bounds data are discussed in volume 1 of this Technical Paper.

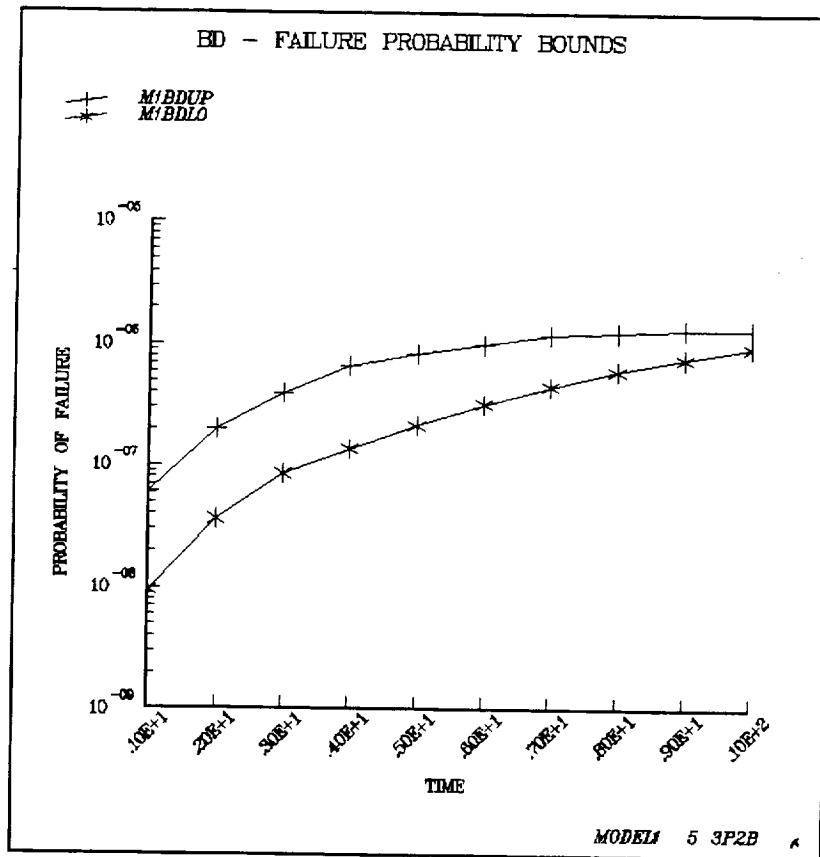


Figure 4. Probability of failure bounds for a single model.

2.3. Worst-Case Bounds Data

Figure 5 shows the worst-case data for MODEL1 version 1 from file CMMPTR2.RS1. The screen shows four graphs of worst-case failure state data. The key at the top left identifies the graphs. The top string identifies M1F1WST as MODEL1 failure state 1 (F1) and the worst-case data. The second and third keys represent worst-case data for failure states F2 and F3. The last key represents the worst-case data for the system failure state that caused the system to fail because of the exhaustion of redundant hardware (REXHST). These data resulted from making a modeling truncation approximation to simplify the model solution (see vol. 1 of this TP). Best-case data can also be plotted but is not shown here.

2.4. Summation of State Probabilities

Figure 6 shows the results of the summation of the three state probabilities shown in the key as M1F1+M1F2+M1REXHST for MODEL1 version 5 from file 3P2B.RS5. HARPO allows the user to specify any of the system state probabilities for summation, that is, failure or operational states. This state summation capability can be used to do performability studies or to examine system operational mode probabilities.

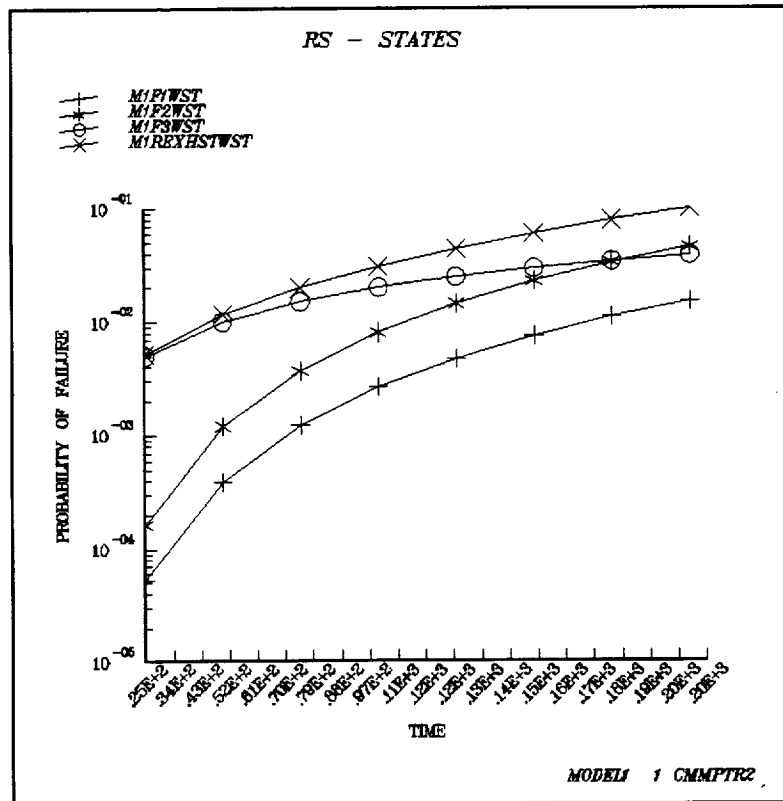


Figure 5. Worst-case bounds data for MODEL1.

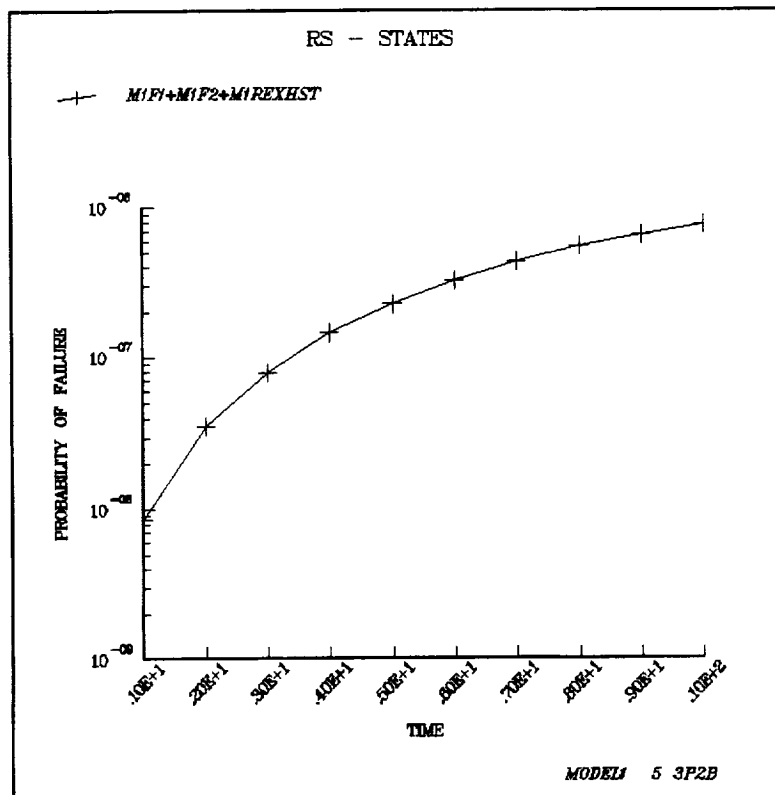


Figure 6. User-specified summation of state probabilities.

2.5. Sensitivity of System Failure

Figure 7 demonstrates HARPO's ability to display sensitivity analyses. In this plot, the MODEL for the system from all activated EX29.RS* files (in this case three versions, one point for each file) was examined for the sensitivity of failure state F to a change in a user-specified failure rate. This rate is shown on the horizontal axis with the fixed mission time of 2 hours. This powerful design trade-off capability enables the user to determine the weak devices in a system that cause the greatest unreliability and thus suggest areas for improvement.

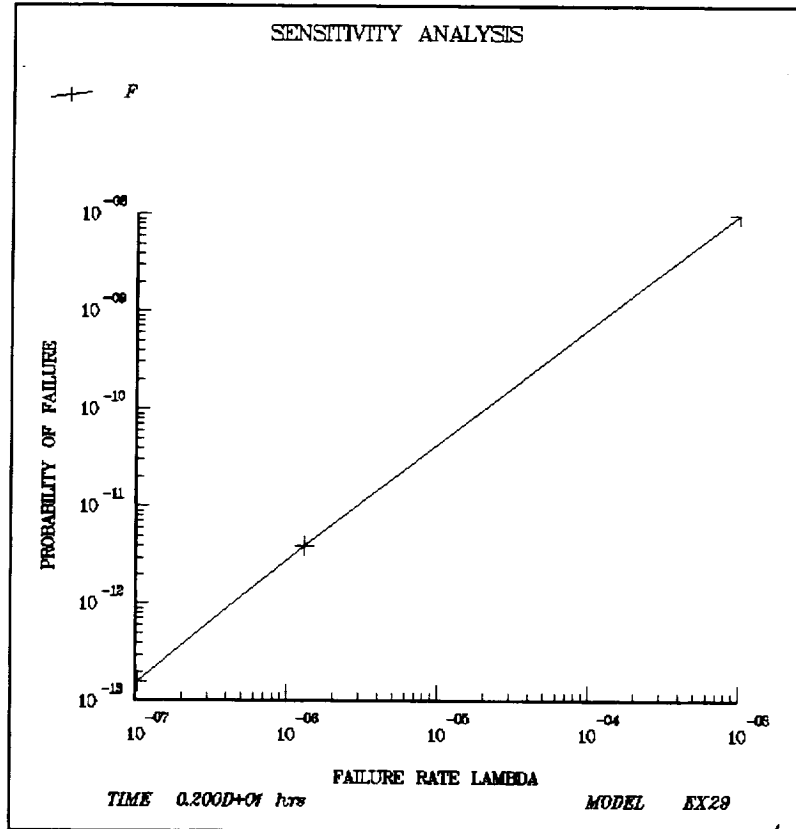


Figure 7. Sensitivity of system failure to variation in failure rate lambda.

Chapter 3

Program Initiation

This chapter discusses workstation specifics pertaining to the program, such as program restrictions due to array limitations and model and data specification conventions. A description of the prompts and menus is provided in chapter 4.

The only output file from HARP that is required as input to HARPO is the results, or RS*, data file for each model. The RS* data file is read and parsed by data type (state) into separate temporary files called plot point (PPT) files. Parsing reduces the extensive RS* data file to a more usable format for HARPO. The RS* data file and its data are not modified in any way, and the file is not destroyed. The user is prompted to specify whether the PPT file should be retained. HARPO provides this option for users who want to import these files into commercial spreadsheet programs. These files are overwritten when HARPO is executed with the same model name. If the user does not request the files, then upon normal termination of an analysis session, all PPT files created are removed from the user's working directory. Thus, the directory remains unaffected. (Note: if the program is terminated abnormally, PPT files may require identification and removal by the user.) Because of the possible length of directory paths, the program should be executed in the directory in which the RS* data files reside.

When HARPO parses the RS file, it creates internal files called PPT (point plot) files. The PPT files are formed by prefixing data files with the letter M and an integer representing the order in which a model is activated. These data specifications are described in chapter 2. When the user selects quit, the user is prompted to save the PPT files. These PPT files are ASCII files that can be imported into many commercial software programs.

HARP allows many special characters to be used for the definition of state names. State tuple notation, which can be used to identify Markov states, uses a comma to delimit tuple values. HARPO prefixes the tuple notation with M and an integer for data specification, and the data specification with a comma becomes a PPT file. Using the comma causes a problem on PC's using DOS because DOS does not allow commas in file names. Consequently, all versions of HARPO convert commas to underscore characters.

3.1. Workstation Specifics

Each workstation varies to some degree in the appearance of its window environment and in the use and manipulation of the items in that window. This section provides the workstation information necessary for the HARPO program.

3.1.1. Sun Microsystems System

The HARPO program must be executed in the window environment. Once logged onto a Sun workstation, execution can be accomplished by entering

```
suntools
```

The `suntools` command can also be executed from the OpenWindows environment with the command `openwin`. With the mouse cursor in the window, change to the desired directory and execute the program by entering the command

```
harpo
```

The program begins by requesting an initial model specification. Figure 8 shows a typical Sun workstation executing a GKS program; the representation shown may differ slightly on each workstation. The standard Sun locator is a three-button mouse whose buttons are designated left, middle, and right. To answer the model specification prompts, move the mouse to position its cursor inside the prompt or menu (input) window at the bottom of the screen, depress the left mouse button, type the response, and then enter a carriage return. All prompts and menus produced by the program appear in this window.

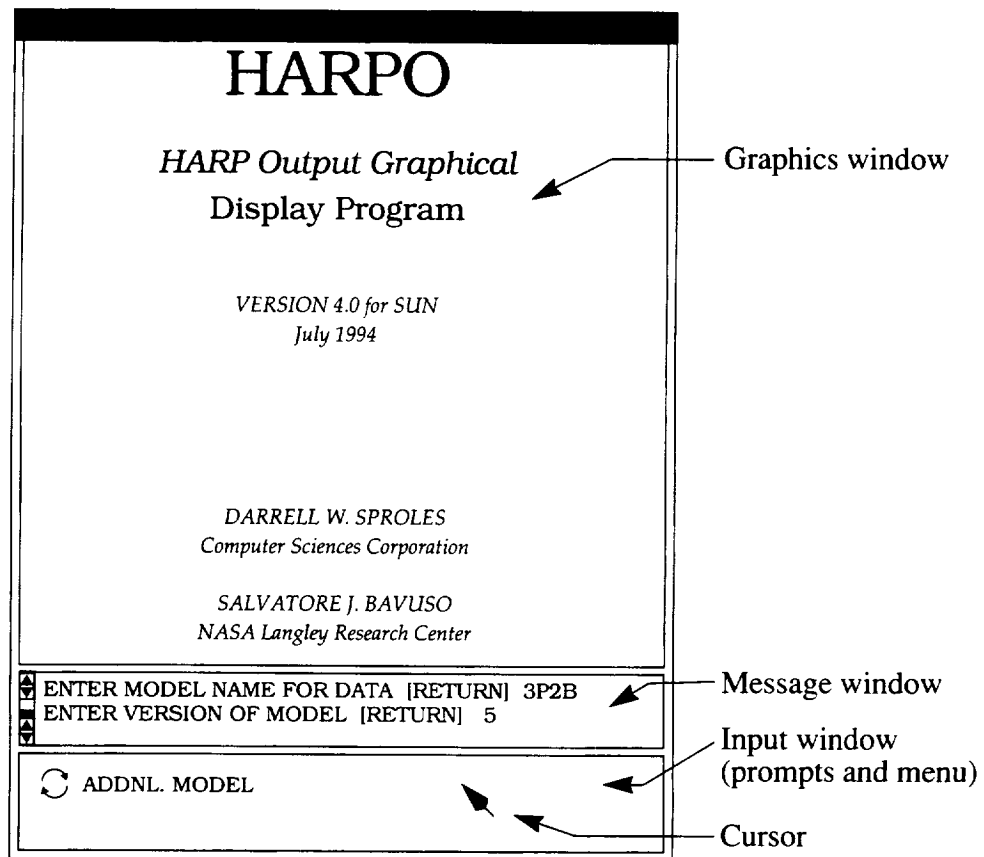


Figure 8. Sun workstation display.

Informative messages appear in the message window directly above the input window. Error messages are written to the input window and require the user to enter a carriage return to continue executing the program. Error messages and prompts move from the input window to the message window after the user responds to them. They remain visible until a new message or prompt scrolls them out of that window. The scroll bar on the left side of this window, along with the mouse, can be used to review the text that has appeared in the window.

When a menu is activated, the choice echo (a circular arrow symbol and the default choice string) is displayed in the input window. The default choice can be selected by positioning the mouse cursor over this string and depressing the left mouse button. To select from the other menu choices, position the cursor over the choice echo. Press and hold the right mouse button down to open the menu. Position the mouse cursor over the desired menu choice and release the right mouse button.

After terminating the program, the user can exit from the window environment by positioning the mouse cursor anywhere in the root window (outside all other windows), pressing and holding the right mouse button down, selecting Exit Suntools (Exit for OpenWindows), and releasing the mouse

button. This command requires confirmation. When prompted, press the left mouse button to confirm or the right mouse button to cancel. The user can then log off the system.

3.1.2. DEC VAXstation II System

The HARPO program must be executed in the window environment, which should be active once logged onto a VAXstation. Set the default directory as desired and execute the program by entering the command

HARPO

The HARPO program begins by requesting an initial model specification. Figure 9 shows a typical workstation executing a GKS program with the VAXstation window environment; the representation shown may differ slightly on each workstation. The standard VAXstation locator is a three-button mouse whose buttons are designated left, middle, and right. To answer the model specification prompts, simply begin typing the response. Trigger completion of string input by entering a carriage return. All program prompts appear in the prompt window, which is activated by the program and deactivated at the completion of each string.

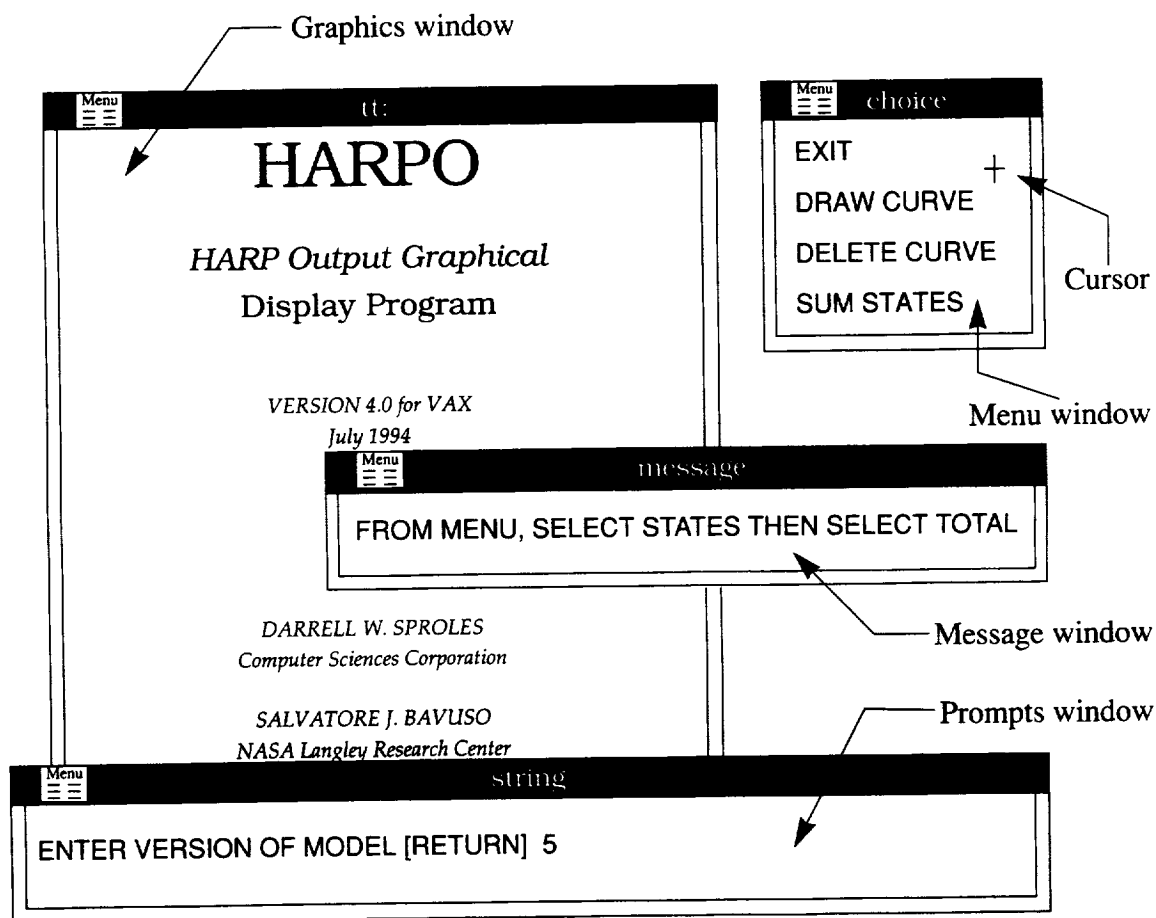


Figure 9. VAXstation window environment display.

Informative messages appear in a message window that the screen manager positions. Each message is written in a separate window. Error messages are written to the prompt window and require the user to enter a carriage return to continue executing the program.

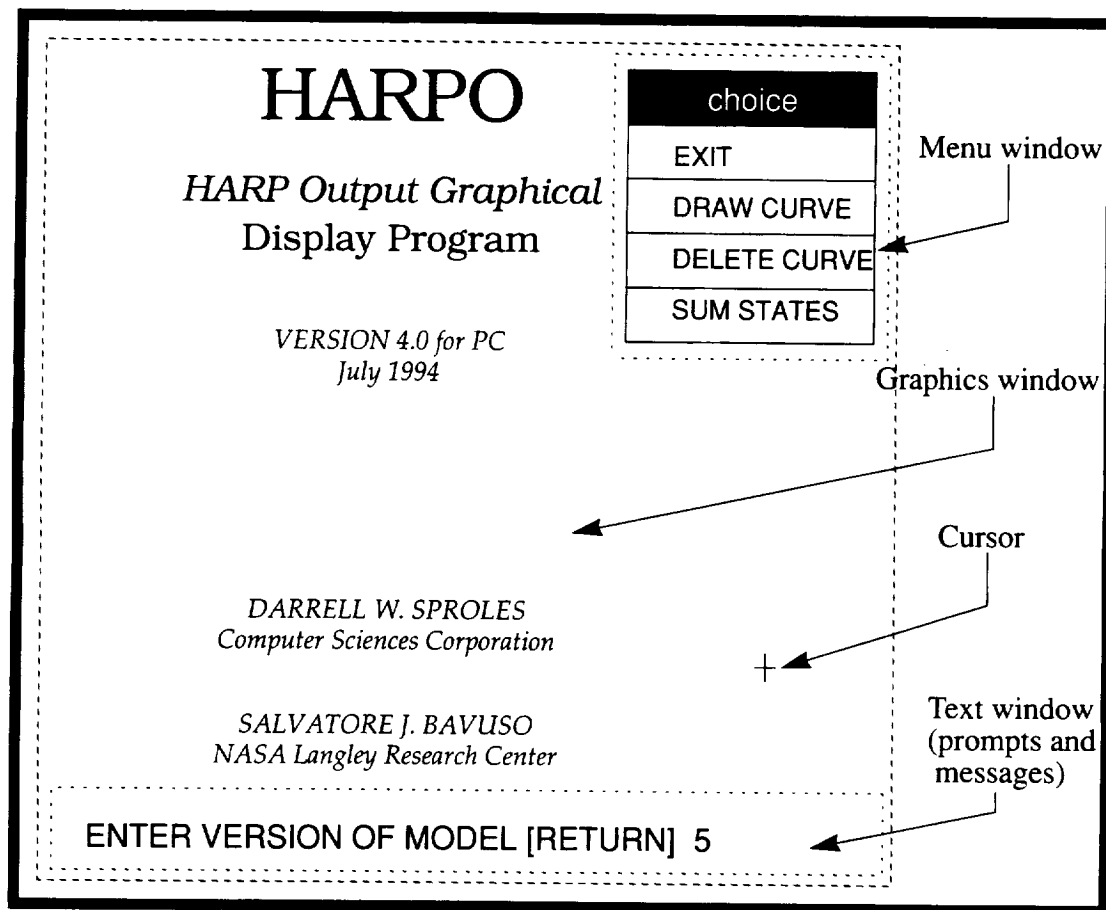


Figure 10. IBM PC executing MSDOS.

When a menu is activated, the choices are displayed in the menu window. To select from the menu options, position the mouse cursor over the desired choice and depress the left mouse button.

The menu icon on the left side of a message window's banner can be used to deactivate (remove) the window. Position the mouse cursor over this icon and depress the left mouse button to open the menu. Select the DELETE option and depress the left mouse button again.

After terminating the program, the user can log off the system.

3.1.3. PC System

The program is executed from the MS DOS environment on the PC. Set the default directory as desired and execute the program by entering the command

HARPO

The program begins by requesting an initial model specification. Figure 10 shows a typical PC executing a GKS program; the representation shown may differ slightly on each PC. The standard PC locator is a two-button mouse whose buttons are designated left and right. To answer the model specification prompts, simply type the response and enter a carriage return. All prompts and messages produced by

the program appear in a specific section of the graphics window located at its base. This prompt window is activated by the program and deactivated at the completion of each string.

Both informative and error messages appear in the prompt window. Error messages require the user to enter a carriage return to continue executing the program.

When a menu is activated, the choices are displayed in the menu section of the graphics window located at the top right corner. To select from the menu choices, position the mouse cursor over the desired choice and depress the left or right mouse button. After terminating the program, the user can leave the PC.

3.2. Naming Conventions

This section explains the program's naming conventions for data files, model and state specifications, and PPT files. HARP RS* data file names consist of three parts: the model name, the characters .RS, and the model version number (an integer from 1 to 9 signified in the formats by *). The model name and version is requested by HARPO and then used to build a model specification. When the program loads a model, an integer is assigned to it and concatenated with the character M (signified in the formats by M#). This number is a counter indicating the order that the model was activated; it is not the same value as the model version number. However, this number is the user's method of associating state data with the model from which it was parsed. State names are any of the state probabilities listed in the RS* data file as well as PT (the plot data), BDLO and BDUP (the bounds data), REXHST (the redundancy exhaustion), and FRATE (the failure rate).

Other extensions are appended to the PT and RS states of a truncated model. These extensions are BST (best case) and WST (worst case). The suffixes used with a FEHM file's failure rate names are TR (transient restoration), PC (permanent coverage), and SF (single-point failure).

- The format and examples of the HARP RS* data file names on a Sun workstation are as follows:

MODEL_NAME.RS*

4P3BTR1.RS1 (Four processors, three buses, transient restoration, first model, first results file)

3P2B.RS5 (Three processors, two buses, fifth results file)

EX29.RS1 (Example number 29, first results file)

EX29.RS3 (Example number 29, third results file)

- The format of the HARP RS* data file names on a VAX workstation differs from the Sun workstation and PC by the attachment of the VAX file version number that is preceded by a semicolon. The format and examples are as follows:

MODEL_NAME.RS*;*

4P3BTR1.RS1;1

3P2B.RS5;2

- The format of the HARP RS* data file names on a PC is similar to the Sun workstation format except that DOS limits truncate model names to eight characters. The format and examples are as follows:

MODEL_NAME.RS*

4P3BTR1.RS1

3P2B.RS5

- The format and examples of HARPO model specifications are as follows:

```
# model_name
1    4P3BTR1
2    EX29
```

- The format and examples of HARPO state names and PPT file names are as follows:

```
M#state_name

M1PT                (MODEL1, point data, system probability of failure)
M3BDUP              (MODEL3, upper simple bound, system probability of failure)
M1F1                (MODEL1, probability of being in failure state number 1)
M7REXHST            (MODEL7, system failure probability hardware exhaustion)
M3FRATE             (MODEL3, system failure probability vs. failure rate variation)
```

- The formats and examples of HARPO state names and PPT file names from a truncated model are as follows:

```
M#state_nameBST

M1PTBST             (MODEL1, point file data, system failure probability, best-case
                    truncated data)
M4F2BST             (MODEL4, probability of failure state number 2, best-case truncated
                    data)

M#state_nameWST

M4REXHSTWST         (MODEL4, system failure probability hardware exhaustion, worst-case
                    truncated data)
M4PTWST             (MODEL4, point data, system failure probability, worst-case truncated
                    data)
```

- The formats and examples of transition rate names from a FEHM file are as follows:

```
FEHMfile_nameTR

FEHM3P2BFT.HRPTR    (FEHM file name, 3P2BFT.HRP, transient restoration data)
FEHMDFEHMTR

FEHMfile_namePC

FEHM3P2BFT.HRPPC     (FEHM file name, 3P2BFT.HRP, permanent coverage data)
FEHMDFEHMPC

FEHMfile_nameSF

FEHM3P2BFT.HRPSF     (FEHM file name, 3P2BFT.HRP, single-point coverage data)
FEHMDFEHMSF
```

3.3. Limits

Certain restrictions apply to the program. These limits are as follows:

Parameter	Limit
Max string buffer size for prompt input	80 char
Max no. of models to be activated/deactivated during an analysis session	9
Max no. of active models for analysis during any point in execution	5
Max no. of PT states from active model	10
Max no. of BD states from active models	10
Max no. of RS states from active models	100
Max no. of curves that can appear on graph at any time	4
Max no. of data points for a curve on any PPT file	50

Chapter 4

Display Directives

Prompts and menus are the two forms of input for the HARPO program. The program prompts the user to enter textual information or select an option from a menu. The user provides the responses to display the desired graph and data.

4.1. Prompts

- ENTER DATA DISPLAY TIME FOR SERIES [RETURN]

The user enters the time of interest for a failure series analysis. An informative message is displayed before this prompt detailing the range of time available for the selected data. The message provides the first time, last time, and increment between times to enable the available times for the data to be derived. The value is entered with any of the real data type descriptors.

- ENTER MODEL NAME FOR DATA [RETURN]

The user enters the model name used in the HARP RS* data file. A string of up to 80 alphanumeric characters is entered.

- ENTER VERSION OF MODEL [RETURN]

The user enters the number associated with the HARP RS* data file that follows the characters .RS. An integer from 1 to 9 is entered.

- ENTER 'Y' TO DRAW PT CURVE [RETURN]

The user indicates whether the PT data associated with the current bounds data is drawn on the same graph. If this action is desired, the character Y is entered; otherwise any other entry (i.e., carriage return) is entered.

4.2. Menus

4.2.1. Main Menu

The options for the main menu, which is shown in figure 11, are described in this section.

EXIT
PT DATA
BD DATA
RS DATA
FAILURE SERIES
DACTV/ACTV_MDL
ADDNL. MODEL

Figure 11. Main menu.

- EXIT

The EXIT option on the main menu terminates GKS, returns the screen to the previous state, and exits the program, which terminates the current session.

- PT DATA

The PT DATA option displays a submenu and item menus for PT data (unreliability) processing. All PT states from the active model(s) are made available through an item menu. The item menu allows the user to choose any PT state available or any curve displayed on the present graph. The user selects from this menu to draw or delete a curve or to exit and return to the main menu. Selecting a state for drawing causes that data to be displayed as a curve on a graph. To enable additional curves to be compared on the graph, a curve can be selected for deletion.

- BD DATA

The BD DATA option displays a submenu and item menus for bounds data processing. All bounds states from the active model(s) are made available through an item menu. The item menu allows the user to choose any active model or any curve displayed on the present graph. Selecting a model for drawing causes both the upper and lower bounds data of that model to be displayed as curves on a graph. Then, the user has the option of having that model's associated PT data displayed as a curve on the same graph. To enable additional curves to be compared on the graph, a curve can be selected for deletion. The bounds are always added to the graph in pairs; however, they are removed singly.

- RS DATA

The RS DATA option displays a submenu and item menus for RS data (probability) processing. All RS states from the active model(s) are made available through an item menu. The item menu allows the user to choose any RS state available or any curve displayed on the present graph. The user selects from the submenu to draw or delete a curve, to sum a series of states then draw as a curve, or to exit and return to the main menu. Selecting a state for drawing causes that data to be displayed as a curve on a graph. To enable additional curves to be compared on the graph, a curve can be selected for deletion. When summing RS states, the choice "TOTAL" is added to the item menu of available states. The user selects all states desired from the item menu and then selects TOTAL to invoke that action.

- FAILURE SERIES

The FAILURE SERIES option displays prompts, a submenu, and item menus for describing a failure rate series to be used for sensitivity analysis. Multiple models of the same name with different version numbers must be active. It produces the following sequence of events:

- A prompt requests the model name to use for selecting data for the series; from the active models, all versions of this name are selected.
- An informative message detailing the range of time available for the selected data appears along with a prompt requesting the time of interest for the failure series analysis. The message should allow the user to derive all available time values. The time value should be entered as a decimal.
- An informative message giving an instruction appears with an item menu of all symbolic failure rate names available for the selected data. Select the failure rate of interest from the item menu.
- The submenu and item menus for performing sensitivity analysis are displayed. The user selects from the submenu to draw or delete a curve or to exit and return to the main menu. The item menus make the PT and all RS states available.

- DACTV/ACTV_MDL

The DACTV/ACTV_MDL option displays an item menu of all active model names with the name of the current model appearing last. The DACTV/ACTV_MDL option allows an active model to be deactivated or replaced. It also displays the EXIT option, which can be used to display the active model names and return to the main menu. The EXIT option can also be used to deactivate a model that has the same name but is incompatible with the failure series being analyzed. To deactivate one of the active models and activate another, select a model from the menu and answer the model specification prompts that follow. A model can be deactivated without a replacement by selecting a model and entering a carriage return in response to each prompt. This action produces the following error message, which can be ignored: ERROR: INVALID ENTRY FOR DEFINING MODEL [HIT RETURN TO CONTINUE].

- ADDNL. MODEL

The ADDNL. MODEL option allows entry of a model specification for loading additional HARP RS* data files into the program for access. Selection of this option is followed by the same prompts as used for initial program entry.

4.2.2. PT DATA, BD DATA, and FAILURE SERIES Submenu

The submenu for PT DATA, BD DATA, and FAILURE SERIES processing is shown in figure 12, and the menu options are described in this section.

EXIT
DRAW CRUVE
DELETE CURVE

Figure 12. Submenu for PT DATA, BD DATA, and FAILURE SERIES.

- EXIT

The EXIT option on the submenu terminates analysis of the present data type; control is returned to the main menu for the user's next selection.

- DRAW CURVE

The DRAW CURVE option displays an item menu of all available states of the desired data type from the active model(s). When an option is selected, a curve representing that data is drawn on the graph. The submenu then reappears on the screen enabling additional curves to be compared or other actions.

- DELETE CURVE

The DELETE CURVE option displays an item menu of all states that are currently drawn on the graph. When an option is selected, the curve representing that data is removed from the graph. The submenu then reappears on the screen enabling additional curves to be compared or other actions.

4.2.3. RS DATA Submenu

The submenu for RS DATA processing is shown in figure 13. All menu options except SUM STATES occur in the previous submenu description, produce the same actions, and are not reiterated.

EXIT
DRAW CURVE
DELETE CURVE
SUM STATES

Figure 13. Submenu for RS DATA.

- SUM STATES

The SUM STATES option displays an item menu of all available states from the active model(s) plus the total option. (See fig. 14.) Displayed along with the item menu is an informative message giving an instruction. When a series of consecutive options are selected followed by the total option, the data for the states selected are summed. That summation is drawn as the only curve on a graph. The submenu then reappears on the screen enabling other actions. If the user selects nonsystem failure states for display, HARPO processes the information correctly; however, the vertical graph label may be a misnomer.

M1F1
M1F2
M1REXHST
total

Figure 14. Example item menu.

Chapter 5

Technical Information

5.1. Requirements

HARPO was designed in compliance with the GKS and ANSI FORTRAN standards to be executable on Sun Microsystems workstations, DEC VAXstation II workstations, and IBM-compatible 286, 386, and 486 PC's. The hardware and software requirements for each of these environments are detailed in this section.

5.1.1. Sun System

Hardware requirements to execute the program are as follows:

- Sun series processor
- Graphics display device (color or monochromatic)
- Mouse

Software requirements⁴ to execute the program are as follows:

- SunView (suntools) or OpenWindows (openwin) environment
- Sun UNIX operating system
- Sun FORTRAN 77 compiler and linker

5.1.2. VAXstation II System

Hardware requirements to execute the program are as follows:

- VAXstation II processor
- Graphics display device (color or monochromatic)
- Mouse

Software requirements to execute the program are as follows:

- DEC GKS Version 4.0 or higher (DEC Graphical Kernel System)
- DEC GKS FORTRAN Binding
- VAXstation Windowing Software version 3.1 (or higher)
- VMS operating system version 4.7 (or higher)
- VAX FORTRAN 77 compiler
- VAX/VMS linker utility

⁴HARPO development used the following:

- SunGKS release 4.1 (Sun Microsystems Graphical Kernel System)
- SunGKS FORTRAN Binding

5.1.3. IBM PC System

Hardware requirements to execute the program are as follows:

- IBM-compatible 286, 386, and 486 PC's
- Enhanced graphics adapter (EGA) or video graphics adapter (VGA) display device (color or monochromatic)
- Mouse

Software requirements to execute the program are as follows:

- DOS operating system version 2.1 (or higher)
- Maximum number of PPT files is 100. Set Files = 100+ in the config.sys file to open the maximum number of files

For the PC, the executable code is distributed; thus, it is not necessary to have the GKS package, the compiler, or the linker available. However, the requirements for HARPO development were as follows:

- GSS*GKS version 2.02 (Graphics Software Systems Graphical Kernel System development package, which includes GSS Computer Graphics Interface and device drivers)
- GSS*GKS FORTRAN Binding
- Microsoft FORTRAN 77 compiler
- Microsoft linker utility

5.2. Installation

To install HARPO on a workstation, the workstation's source must be compiled with FORTRAN 77 and the object code linked with the GKS package to create the executable code. Installation of HARPO on a PC requires a different procedure because the executable code is distributed. The installation area for the executables depends on the user's requirements.

5.2.1. Sun System

On a Sun workstation executing UNIX, installation can be accomplished by entering the following commands:

```
f77 harpo.f -o harpo -Bstatic -l/usr/gks4.1/include/gks -l/usr/
openwin/include \ -L/usr/openwin/lib -L/usr/gks4.1/lib -lgks -lxview
-lolgx -lX11 -lxgl -lm
```

The source file for the Sun is harpo.f. It is assumed that directory SunGKS release 4.1 has been installed under directory /usr/gks4.1.

5.2.2. VAXstation II System

On a VAXstation II workstation executing VMS, installation can be accomplished by entering the following command lines:

```
FOR VAXHARPO.FOR
LINK VAXHARPO.OBJ, SYS$LIBRARY:GKSFORBND/LIBRARY
@HARPO
```


The source file for the VAX is VAXHARPO.FOR. It is assumed that the DEC GKS FORTRAN Binding has been installed on SYS\$LIBRARY:GKSFORBND.

5.2.3. IBM PC System

On a PC executing DOS, installation and GSS*GKS configuration can be accomplished by referencing the sample commands and following these instructions:

```
COPY HARPO.EXE [inst_dir]HARPO.EXE
```

1. Create a CGI.CFG file for the computer graphics interface configuration file containing the device driver specifications and the logical device name assignments for the device drivers.
2. Create a KERNEL.SYS file identifying the workstation types that HARPO can access.
3. Edit the AUTOEXEC.BAT file as follows: Modify the PATH variable to specify the HARPO installation directory, insert an environmental path where the file CGI.CFG is found, insert the GSS*GKS environment variable assignments, and insert the command to run the GSS*GKS Device Driver Management Utility DRIVERS.EXE to initialize the subsystem.
4. Create a HARPO.BAT file to establish the GSS*GKS transient drivers, execute the HARPO program, and remove the transient drivers when the program terminates.

The executable file for the PC is HARPO.EXE. It is assumed that the GSS*GKS drivers, the CGI.CFG file, and the KERNEL.SYS file are being installed on C:\GSS\CGI. Example file contents are as follows:

- Example CGI.CFG file contents

```
;
; GSS*GKS device driver specifications using transient switch
;
DRIVER=C:\GSS\CGI\GSSCGI.SYS /T
;
DRIVER=C:\GSS\CGI\IBMEGA.SYS /G:CRT
DRIVER=C:\GSS\CGI\MSMOUSE.SYS /G:INPUT
;
; GSS*GKS logical device name assignments for the device drivers
;
DISPLAY=IBMEGA
MOUSE=MSMOUSE
```

- Example KERNEL.SYS file contents

```
0: WISS
1: DISPLAY; MOUSE
```

- Example AUTOEXEC.BAT file contents

```
ECHO OFF
REM Run GSS*GKS Device Driver Management Utility
```

```

REM to initialize system and install transient drivers
REM
PATH=%PATH%;C:\GSS\CGI
SET CGIPATH=C:\GSS\CGI
C:\GSS\CGI\DRIVERS.EXE
REM
REM Define GSS*GKS paths with environment variables
REM
SET KERNEL=C:\GSS\CGI
SET FONTS=C:\GSS\CGI
SET GMO=C:\GSS\CGI
SET GMI=C:\GSS\CGI
SET CURSORMODE=TRUE
REM
REM Append PATH to include HARPO installation
REM
PATH=%PATH%;C:\HIREL\HARPO

```

- **Example HARPO.BAT file contents**

```

REM
REM Establish transient drivers and begin execution of HARPO
REM
ECHO OFF
C:\GSS\CGI\DRIVERS /Q
HARPO.EXE
C:\GSS\CGI\DRIVERS /R/Q

```

NASA Langley Research Center
 Hampton, VA 23681-0001
 September 27, 1994

Appendix A

Example Session

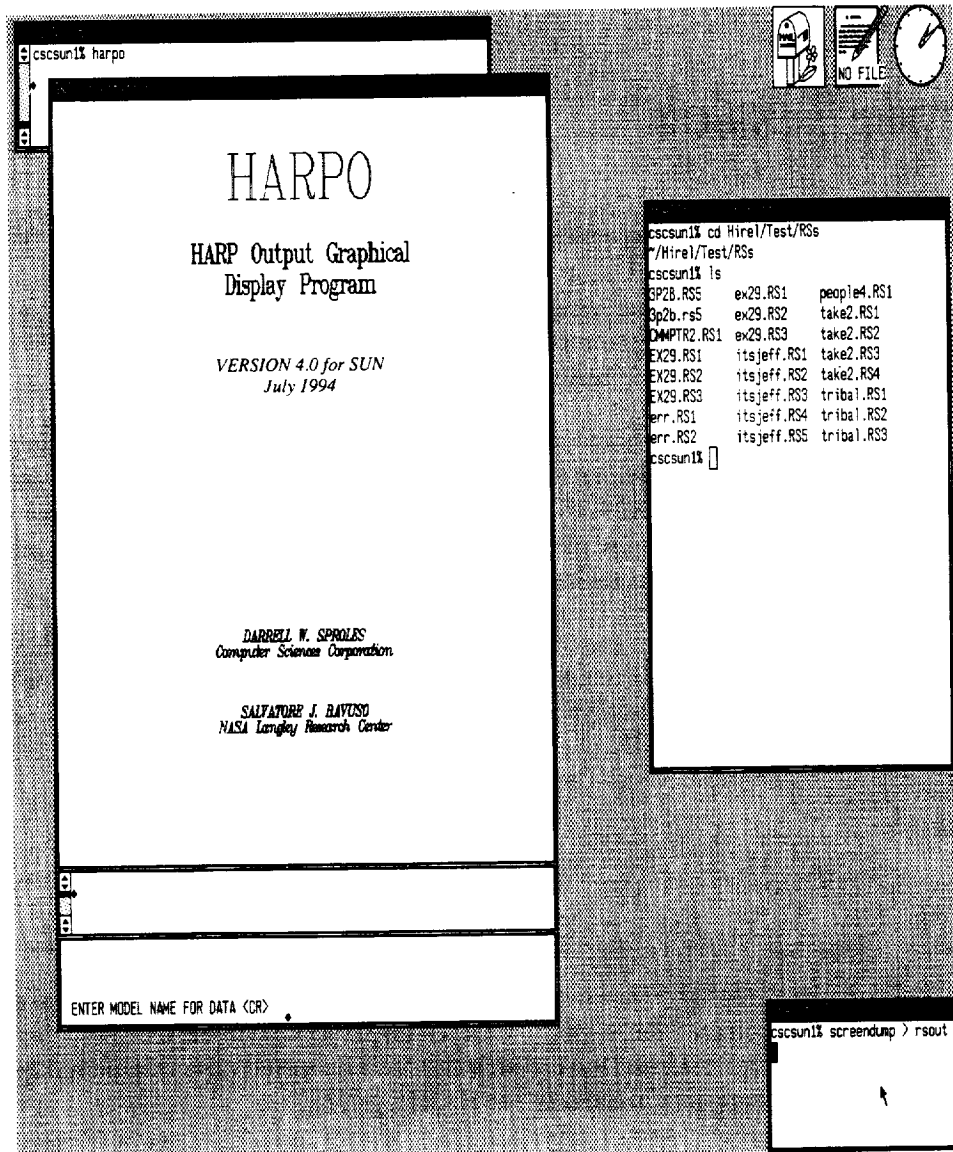
This appendix contains an example session that illustrates all features of HARPO. The example session was performed on a Sun workstation executing UNIX. The curves should appear the same regardless of each workstation's layout, background, and foreground colors. Executing this example requires the user to be familiar with the prompts and menus on the target platform. Thus, the section on workstation specifics should be reviewed before starting this session.

UNIX is case sensitive, so the user should be aware that HiRel typically creates uppercase file names. The data files to use with this session are included with the program distribution. The file names are as follows: 3P2B.RS5, CMMPTR.RS1, EX29.RS1, EX29.RS2, and EX29.RS3. Although the models these files represent are actual system models, they were chosen arbitrarily to demonstrate the HARPO capability. The details of the models are not important for the purposes of this example.

Before starting the session, copies of the data files should be placed in a directory owned by the user. Begin by moving to that directory, and listing the files if desired. Listing files is a good practice because HARPO does not have the capability to display data file names available for activation and analysis. Then execute the program. With UNIX, these steps can be accomplished by entering the following commands:

```
cd data_path
ls
harpo
```

The first display is the credits screen and is shown in the following figure. To complete the session execute the instructions and compare the displays included on the following pages. Some intermediate displays produced by this example session are not included in this appendix. Be certain that the cursor is placed within the HARPO screen area in order to use HARPO.

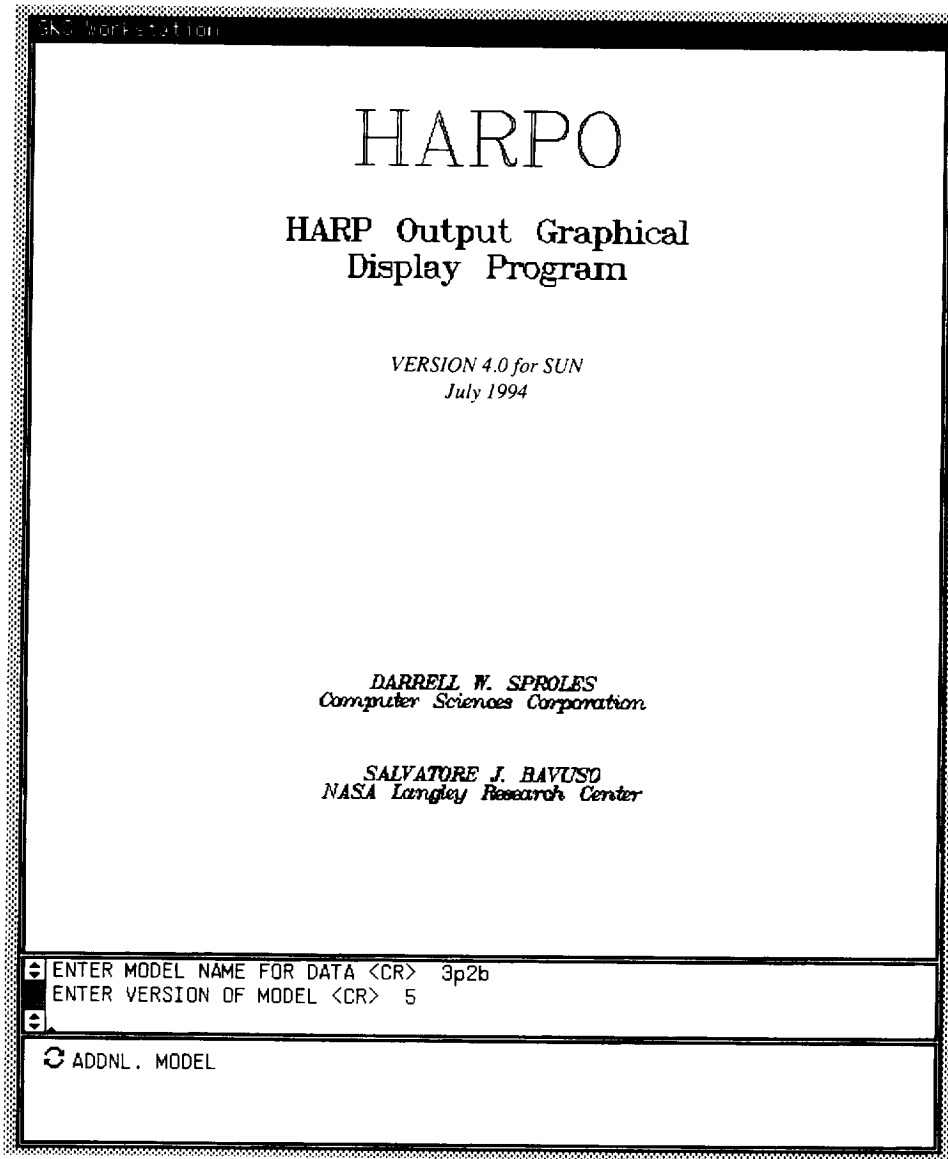


Enter with keyboard the model name: 3p2b

Enter with keyboard the model version: 5

See next page for results.

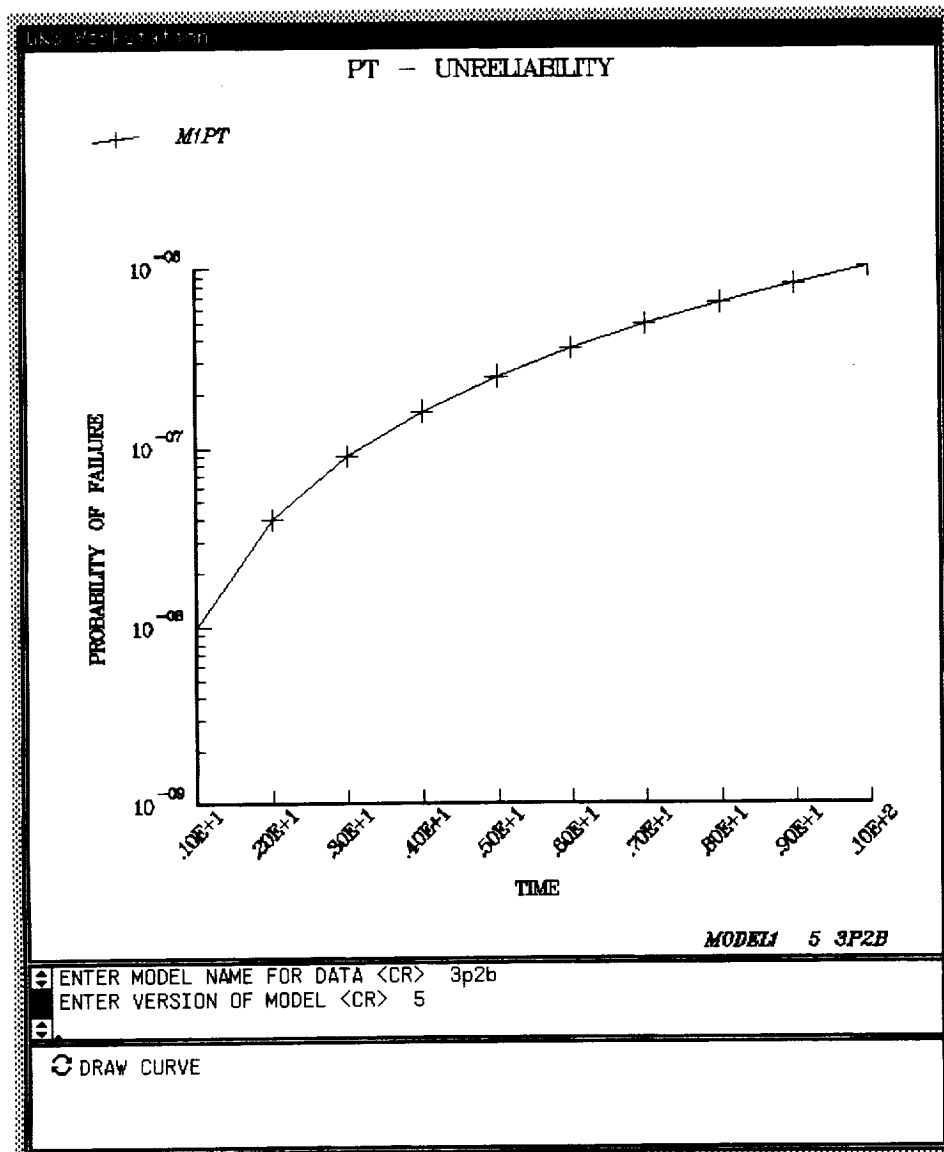
To enter prompted items, type the appropriate response and select the carriage return. To select menu options, point to the symbol with the cursor by moving the mouse, press and hold the mouse button (Sun uses right button, others use left), move the mouse to your right, highlight the selected item, and release the button.



Select with mouse from the main menu: PT DATA
 Select with mouse from the submenu: DRAW CURVE
 Select with mouse from the item menu: M1PT

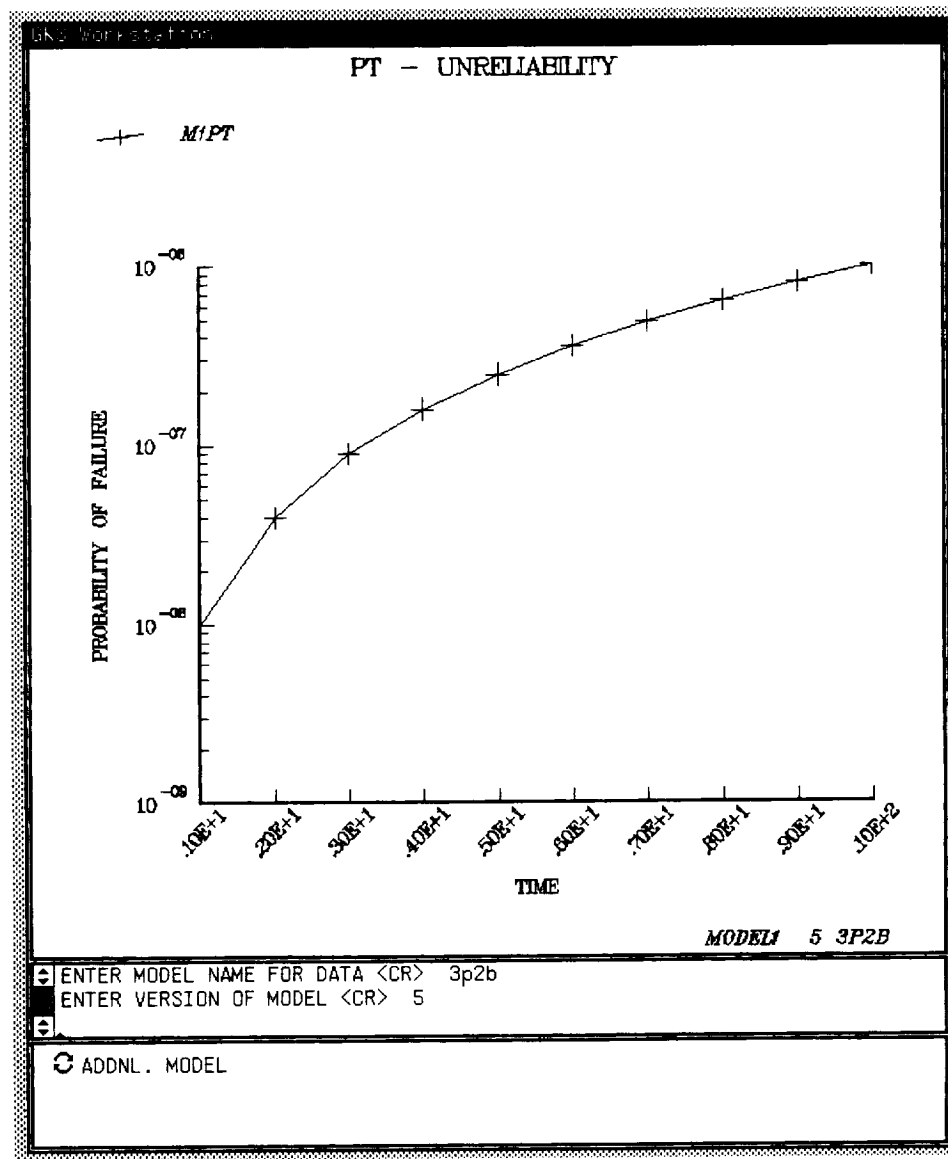
See next page for results.

For instance, position the cursor on the main menu symbol ADDNL. MODEL, press and hold the right mouse button, drag the mouse to activate PT DATA, and release. Repeat these steps for the submenu to activate DRAW CURVE, then repeat these steps for the item menu to activate M1PT. These instructions display the point data (unreliability) for the first model, which corresponds to the fifth version of the model name 3P2B from the 3P2B.RS5 file.



Select with mouse from the submenu: EXIT

See next page for results.

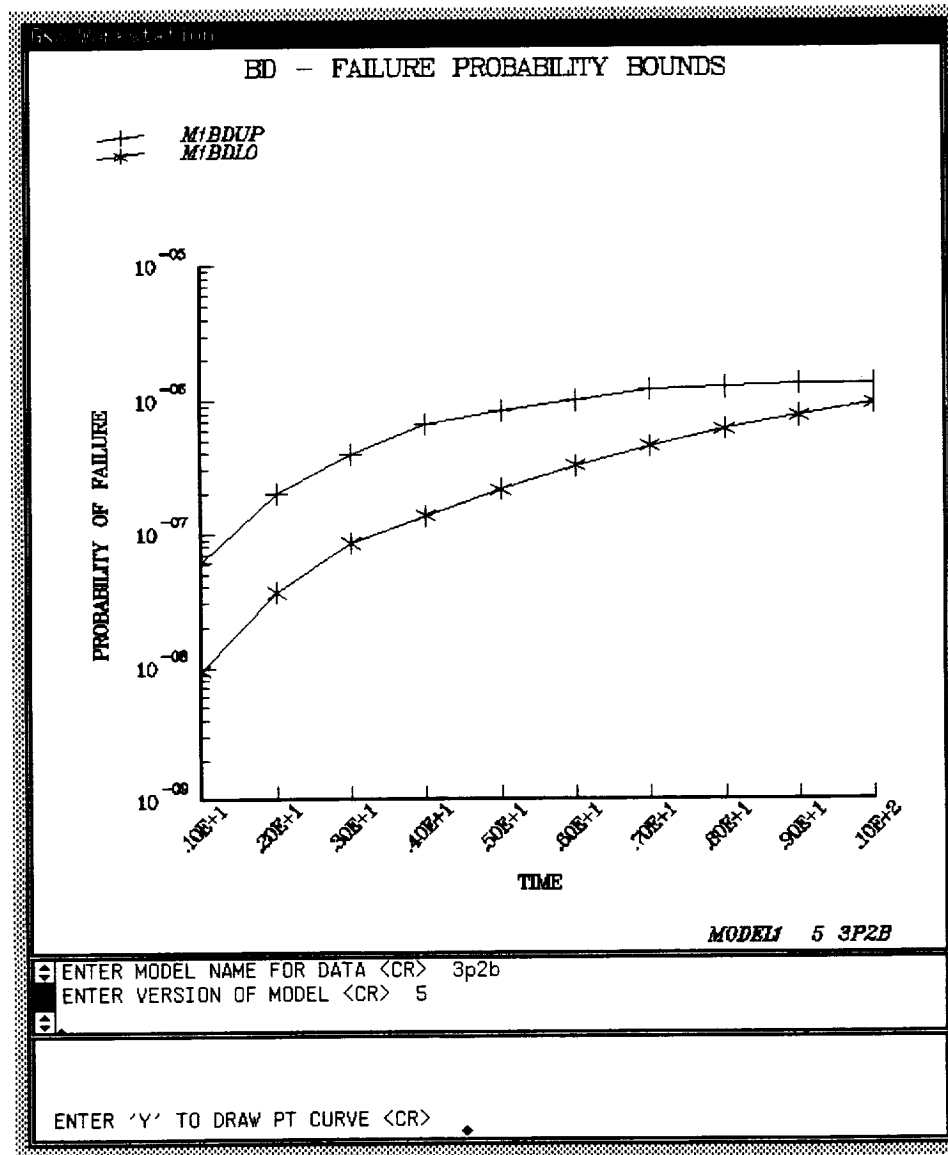


Select with mouse from the main menu: BD DATA

Select with mouse from the submenu: DRAW CURVE

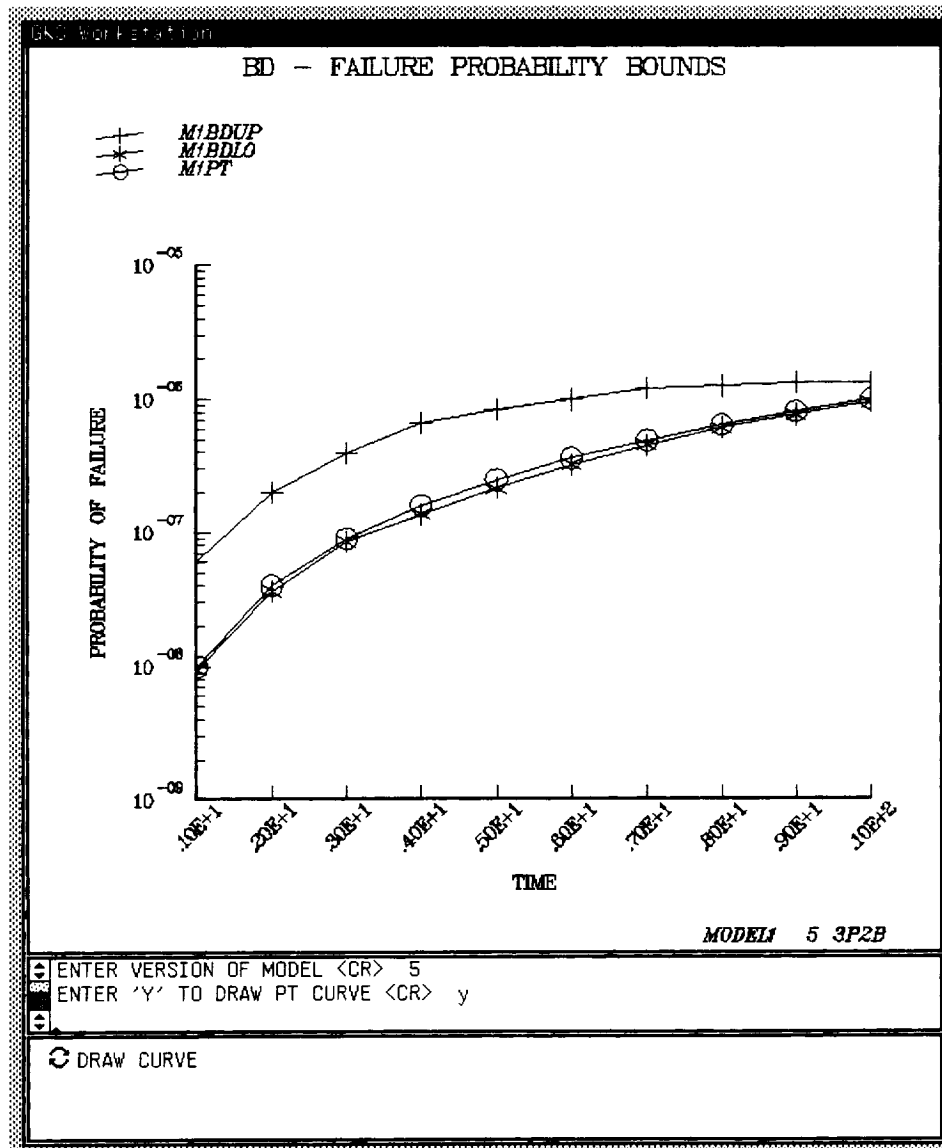
Select with mouse from the item menu: 5 3p2b

See next page for results.



Enter with keyboard the query: y

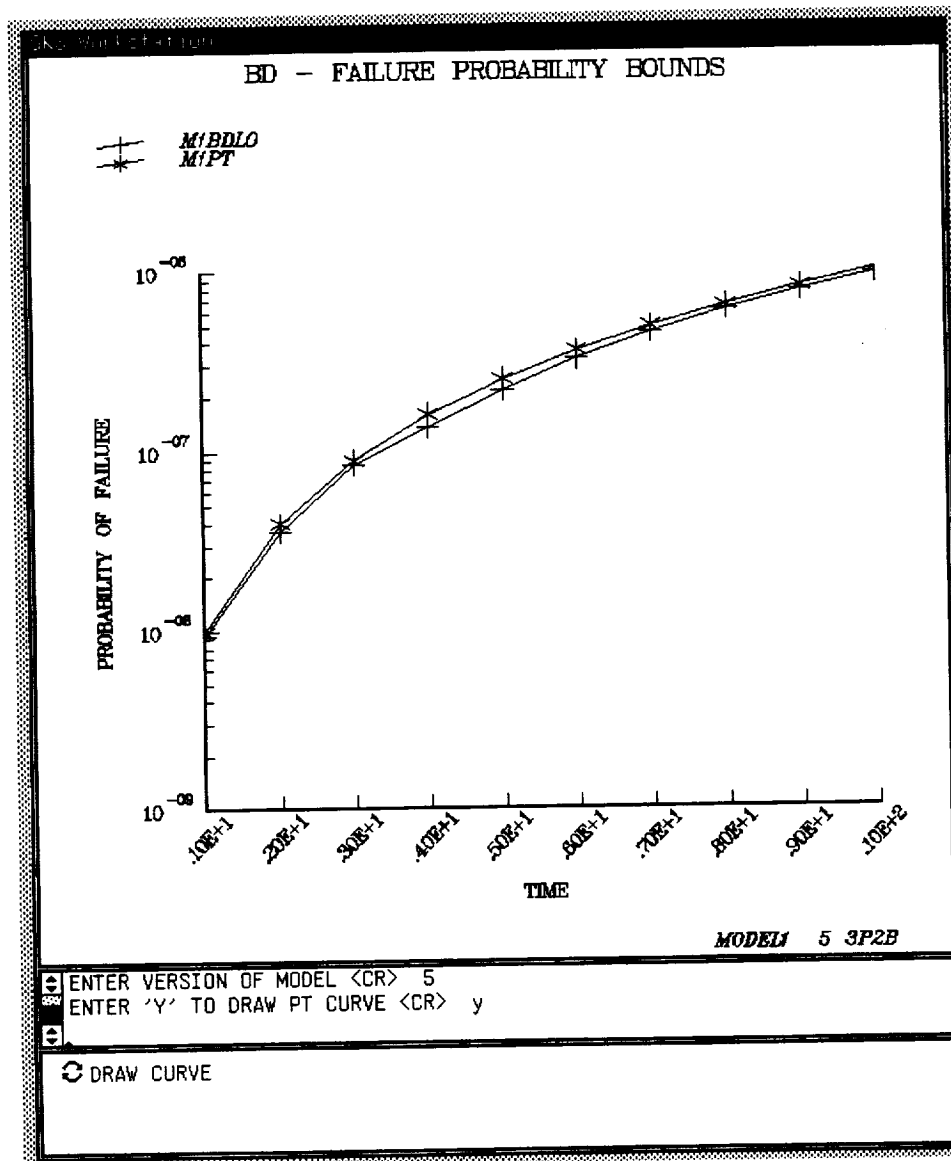
See next page for results.



Select with mouse from the submenu: DELETE CURVE

Select with mouse from the item menu: M1BDUP

See next page for results.



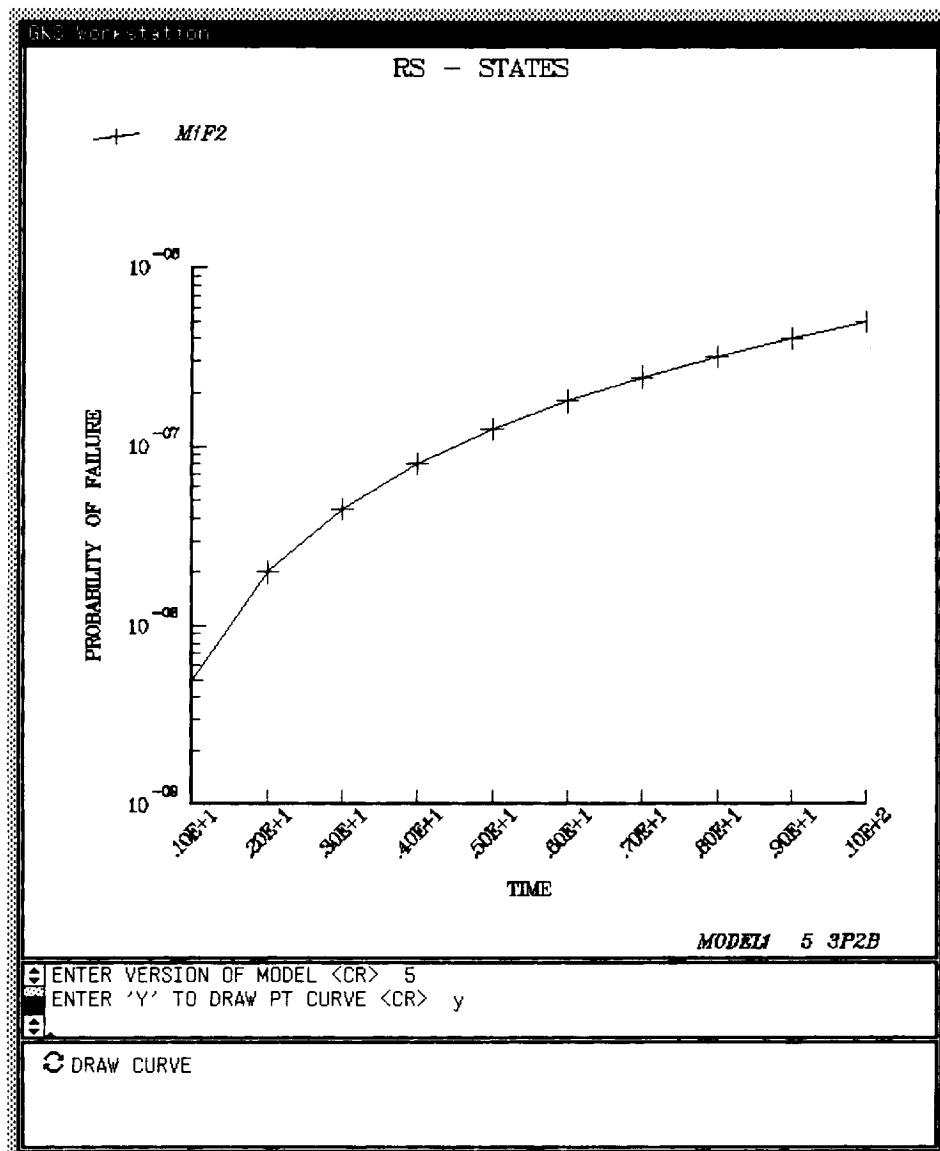
Select with mouse from the submenu: EXIT

Select with mouse from the main menu: RS DATA

Select with mouse from the submenu: DRAW CURVE

Select with mouse from the item menu: M1F2

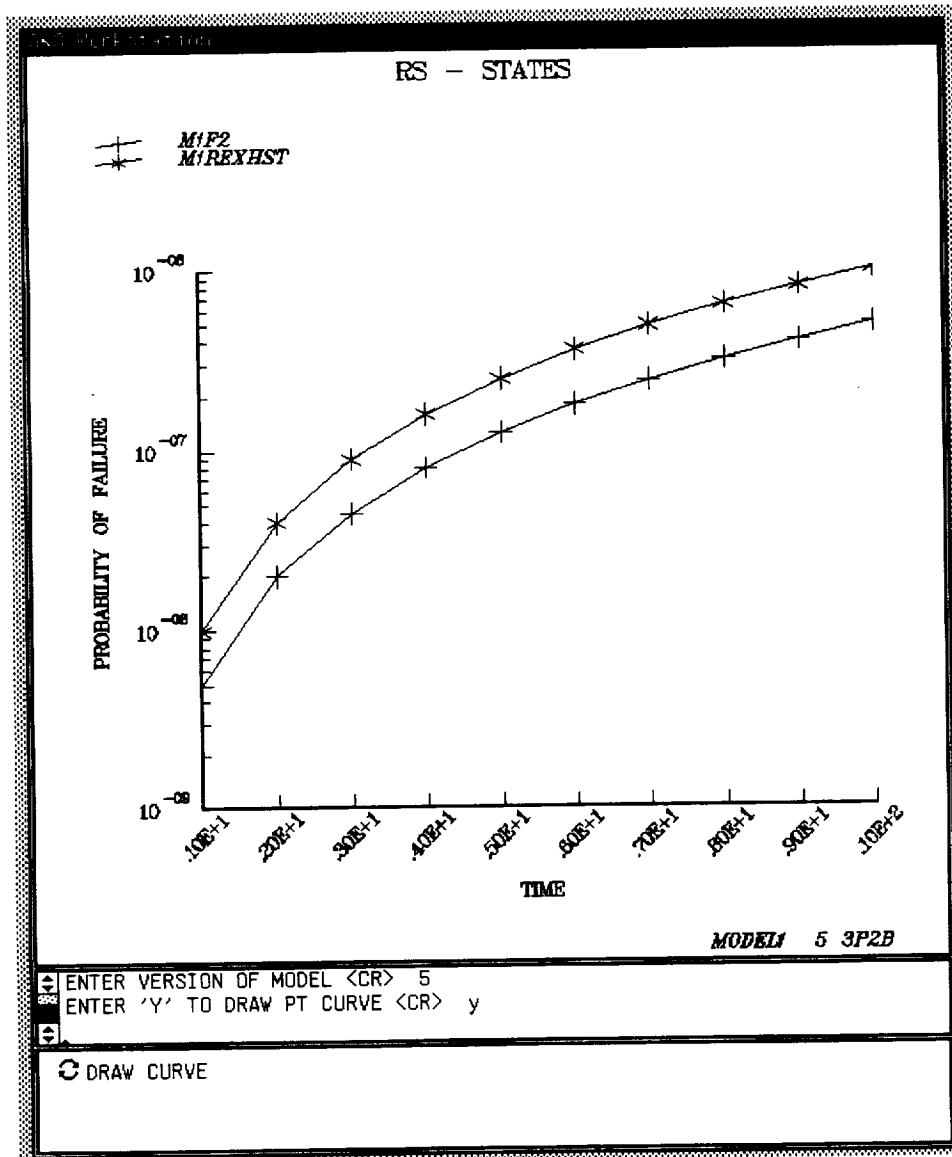
See next page for results.



Select with mouse from the submenu: DRAW CURVE

Select with mouse from the item menu: M1REXHST

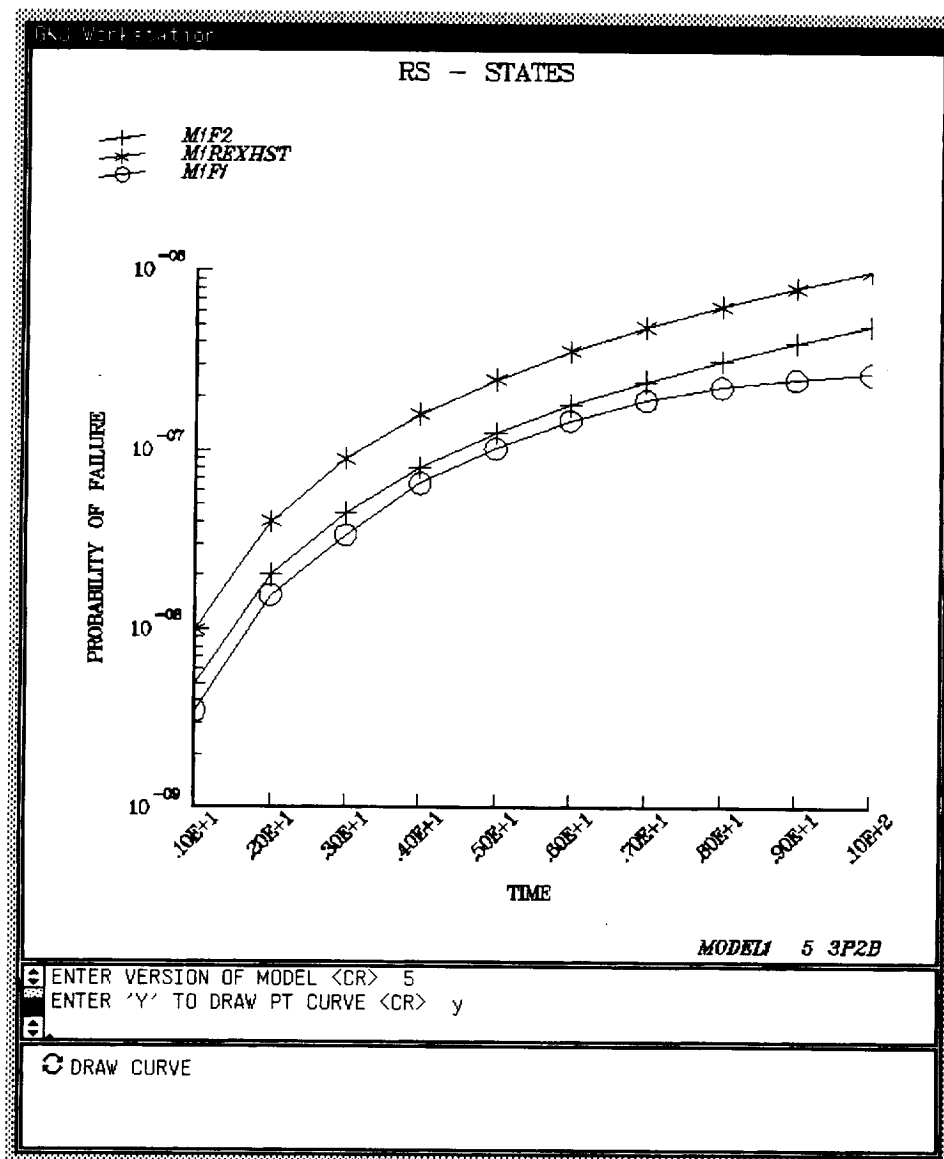
See next page for results.



Select with mouse from the submenu: DRAW CURVE

Select with mouse from the item menu: M1F1

See next page for results.



Select with mouse from the submenu: SUM STATES

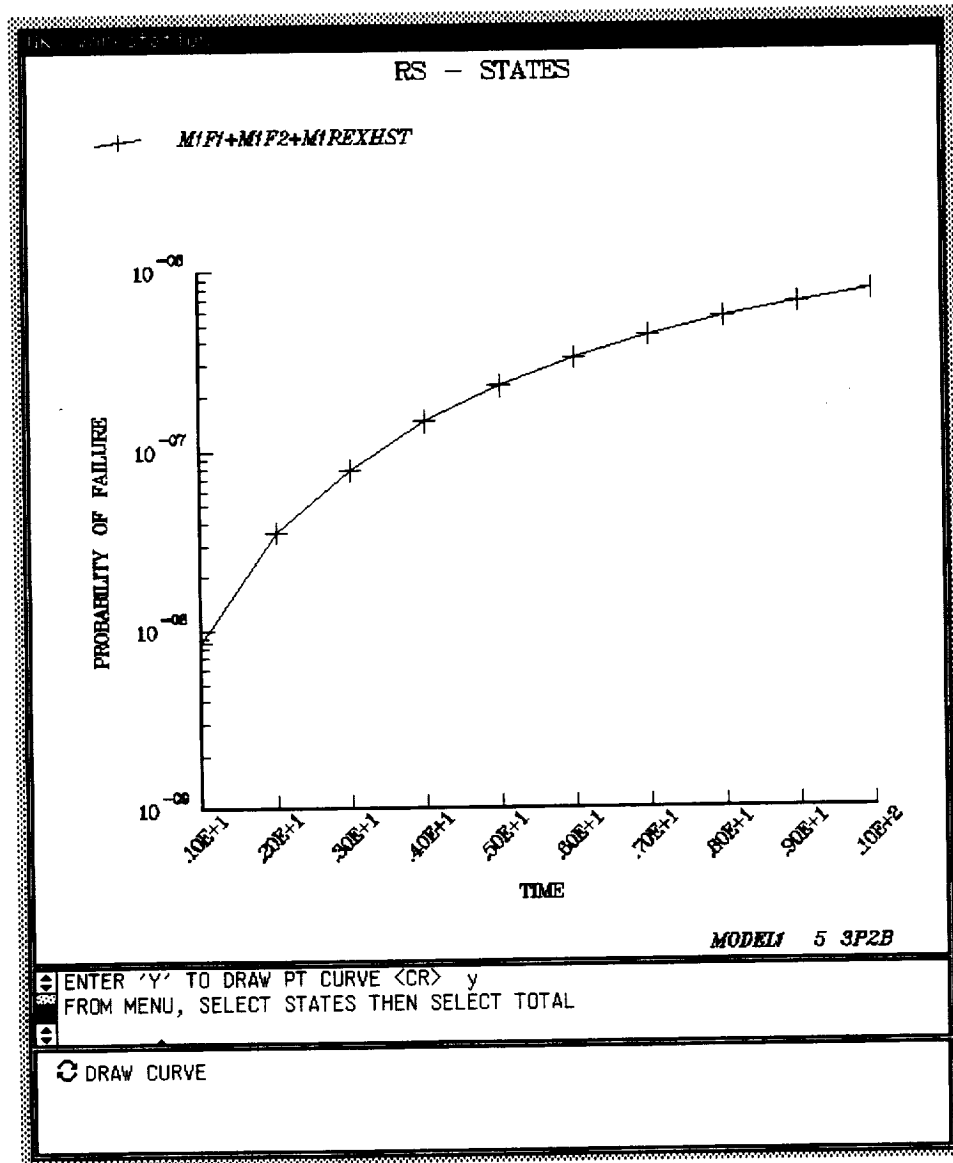
Select with mouse from the item menu: M1F1

Select with mouse from the item menu: M1F2

Select with mouse from the item menu: M1REXHST

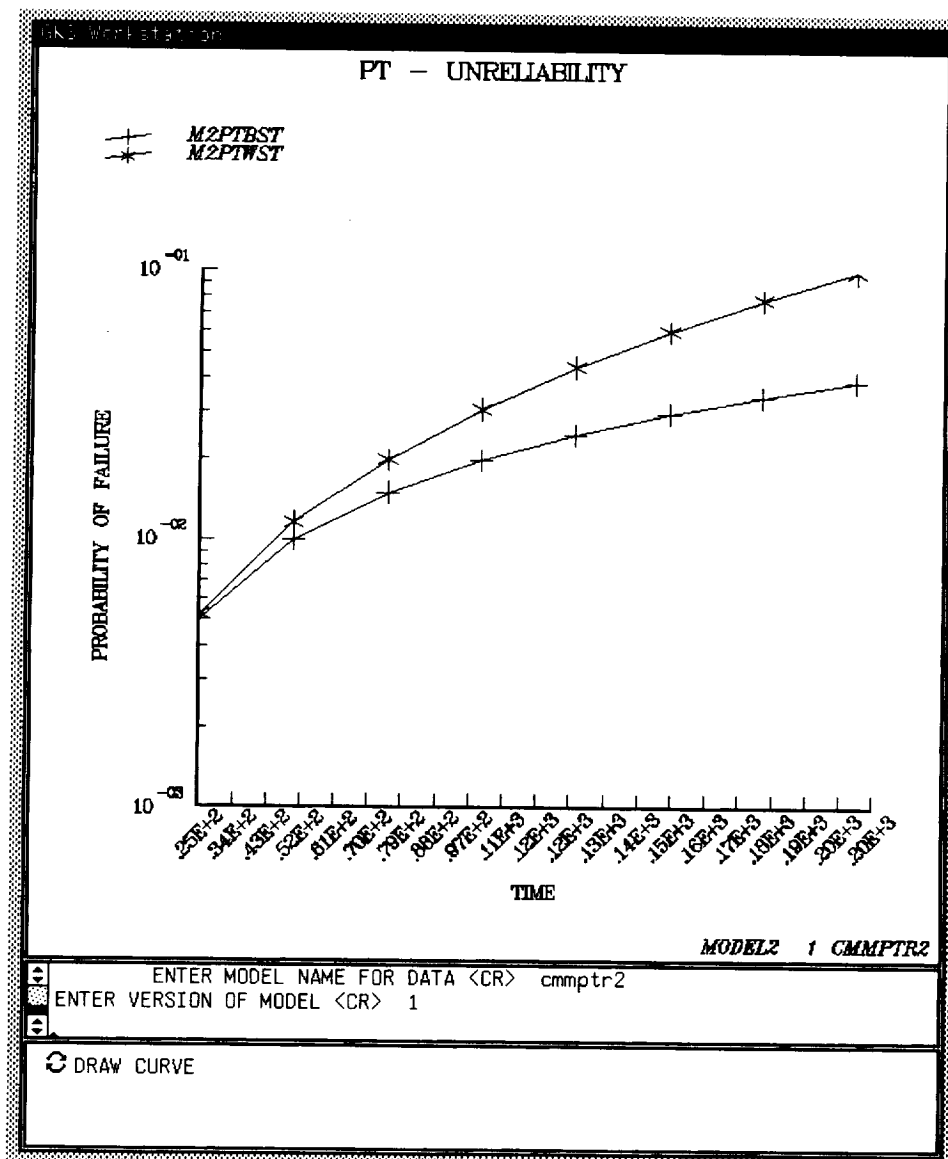
Select with mouse from the item menu: total

See next page for results.



Select with mouse from the submenu:	EXIT
Select with mouse from the main menu:	DACTV/ACTV_MDL
Select with mouse from the item menu:	5 3p2b
Enter with keyboard the model name:	cmmpt2
Enter with keyboard the model version:	1
Select with mouse from the main menu:	PT DATA
Select with mouse from the submenu:	DRAW CURVE
Select with mouse from the item menu:	M2PTBST
Select with mouse from the submenu:	DRAW CURVE
Select with mouse from the item menu:	M2PTWST

See next page for results.



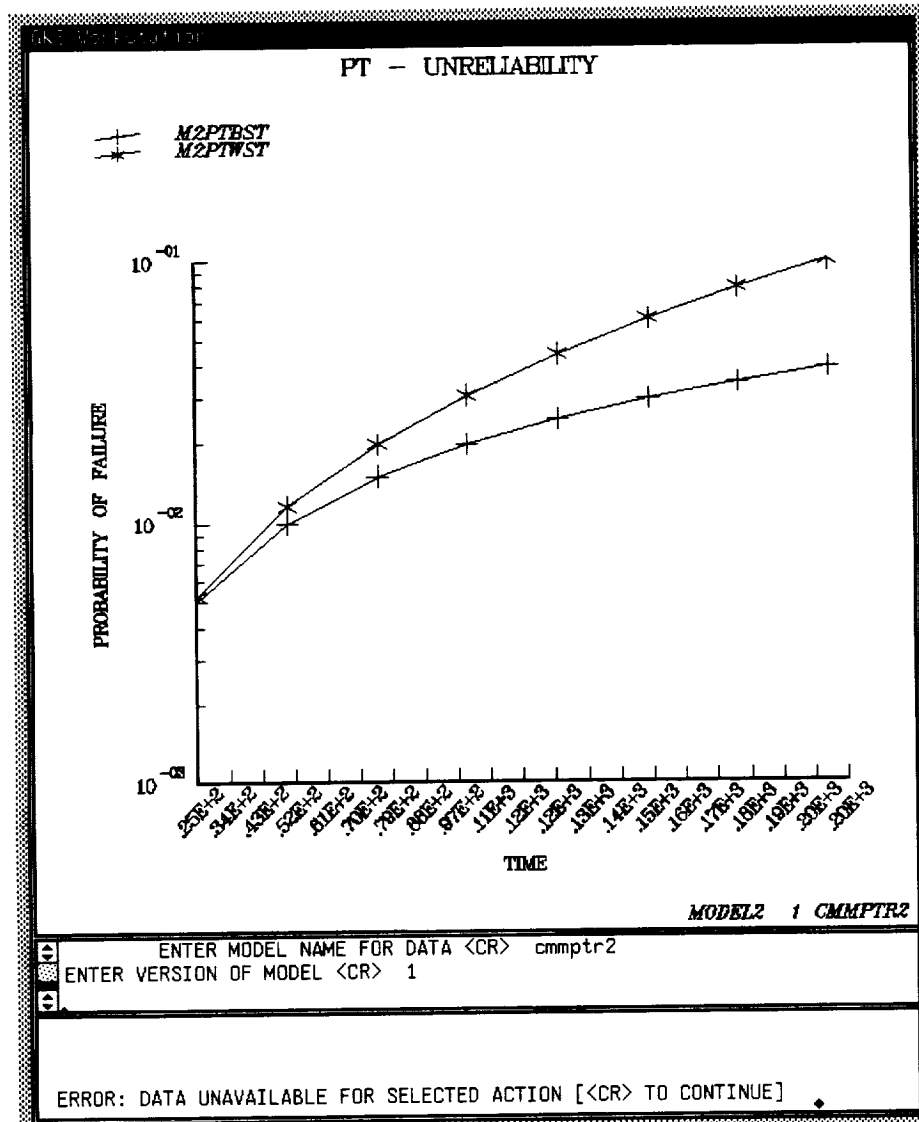
Select with mouse from the submenu: EXIT

Select with mouse from the main menu: BD DATA

Select with mouse from the submenu: DRAW CURVE

See next page for results.

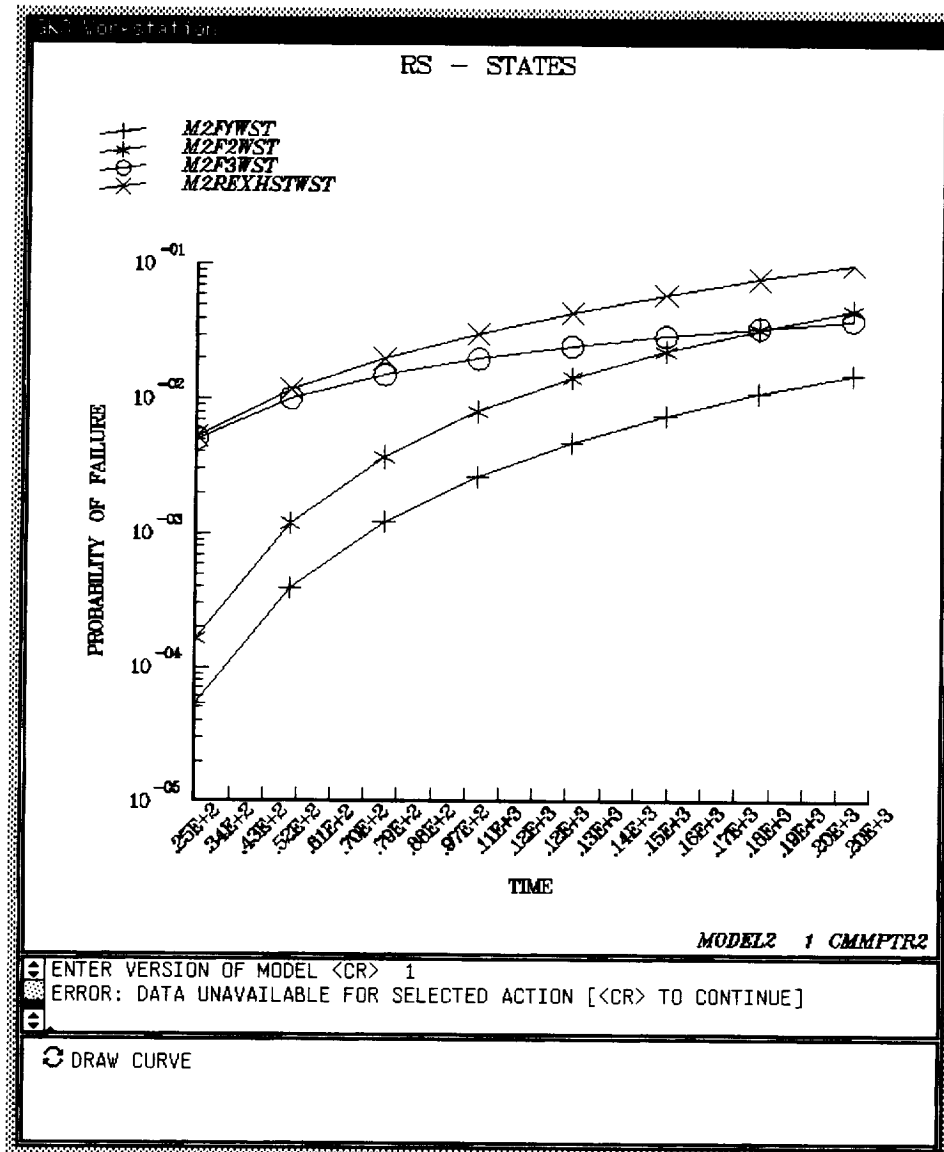
The RS file from this model does not contain BD data (parametric bounds), so it is unavailable. This exercise demonstrates HARPO's response to a request to display an item for which data does not exist.



Respond to the message with a carriage return.

Select with mouse from the submenu:	EXIT
Select with mouse from the main menu:	RS DATA
Select with mouse from the submenu:	DRAW CURVE
Select with mouse from the item menu:	M2F1WST
Select with mouse from the submenu:	DRAW CURVE
Select with mouse from the item menu:	M2F2WST
Select with mouse from the submenu:	DRAW CURVE
Select with mouse from the item menu:	M2F3WST
Select with mouse from the submenu:	DRAW CURVE
Select with mouse from the item menu:	M2REXHSTWST

See next page for results.



Select with mouse from the submenu: DELETE CURVE

Select with mouse from the item menu: M2F1WST

Select with mouse from the submenu: DELETE CURVE

Select with mouse from the item menu: M2F3WST

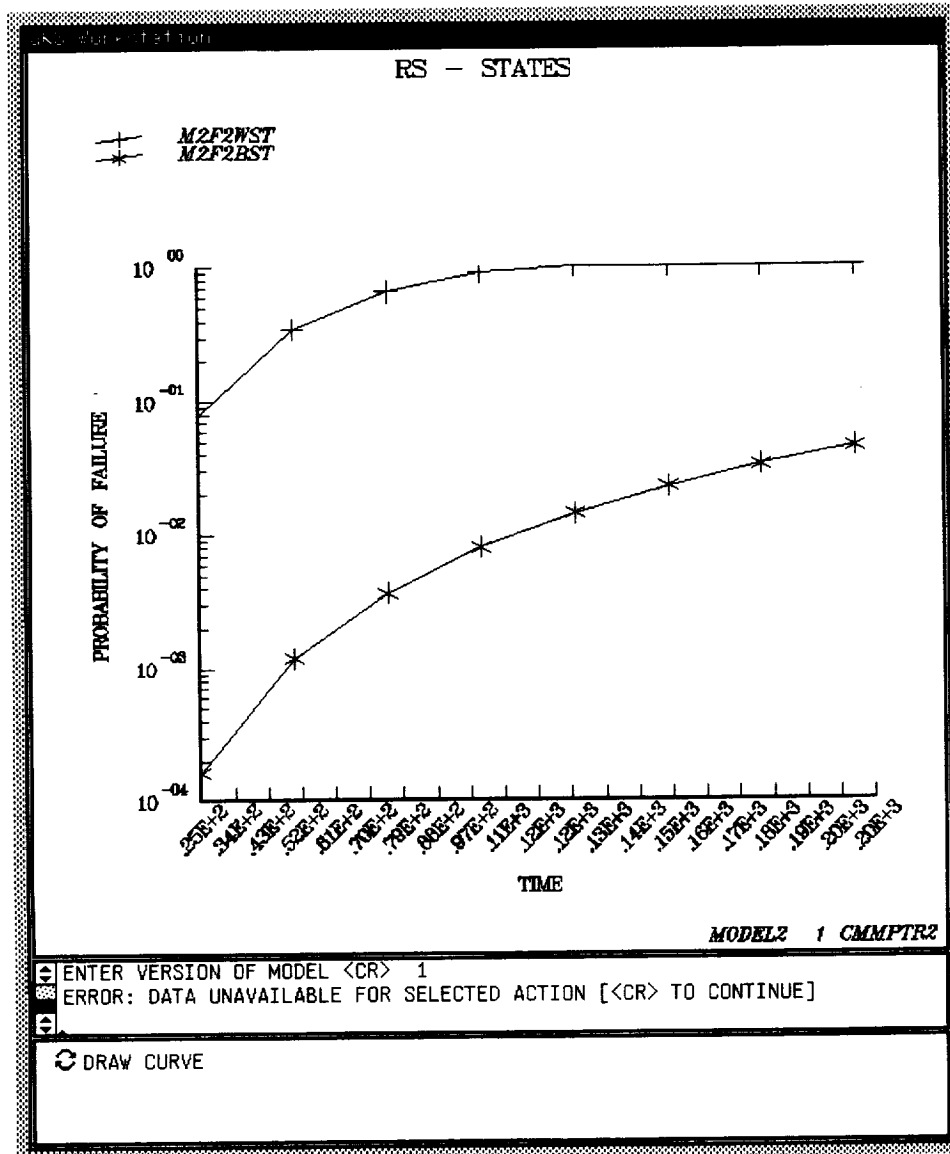
Select with mouse from the submenu: DELETE CURVE

Select with mouse from the item menu: M2REXHSTWST

Select with mouse from the submenu: DRAW CURVE

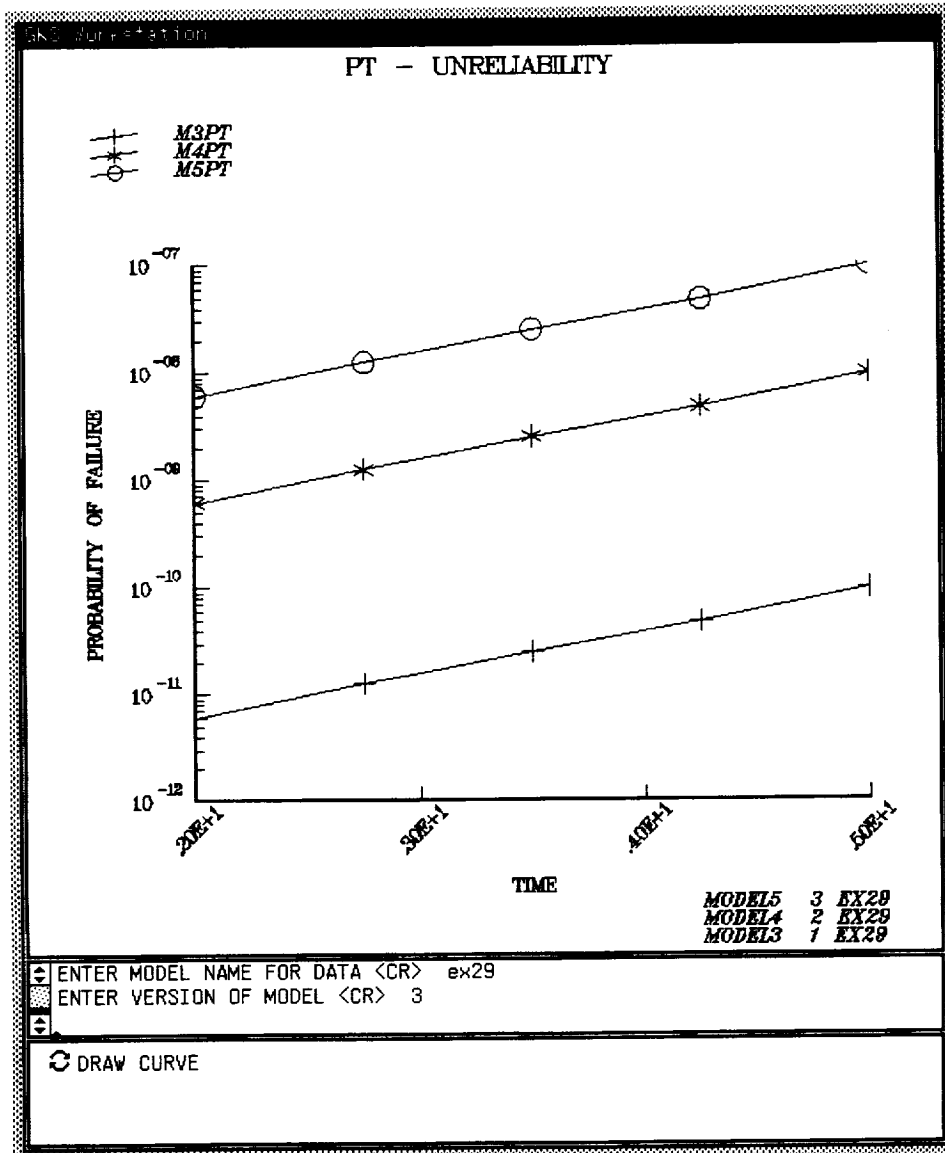
Select with mouse from the item menu: M2F2BST

See next page for results.



Select with mouse from the submenu:	EXIT
Select with mouse from the main menu:	DACTV/ACTV_MDL
Select with mouse from the item menu:	1 cmmptr2
Enter with keyboard the model name:	ex29
Enter with keyboard the model version:	1
Select with mouse from the main menu:	ADDNL. MODEL
Enter with keyboard the model name:	ex29
Enter with keyboard the model version:	2
Select with mouse from the main menu:	ADDNL. MODEL
Enter with keyboard the model name:	ex29
Enter with keyboard the model version:	3

Select with mouse from the main menu:	DACTV/ACTV_MDL
View item menu to examine available models.	
Select with mouse from the item menu:	EXIT
Select with mouse from the main menu:	PT DATA
Select with mouse from the submenu:	DRAW CURVE
Select with mouse from the item menu:	M3PT
Select with mouse from the submenu:	DRAW CURVE
Select with mouse from the item menu:	M4PT
Select with mouse from the submenu:	DRAW CURVE
Select with mouse from the item menu:	M5PT
See next page for results.	



Select with mouse from the submenu: EXIT

Select with mouse from the main menu: RS DATA

Select with mouse from the submenu: SUM STATES

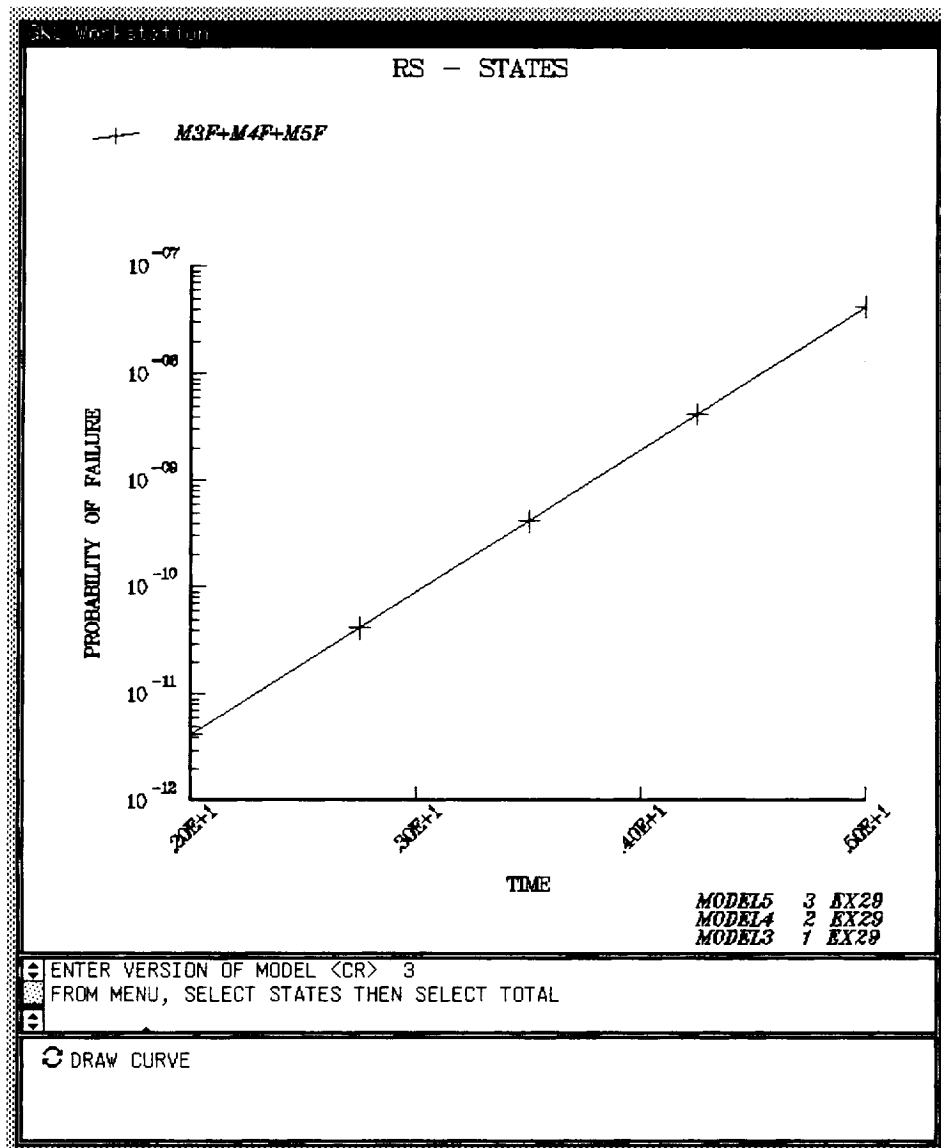
Select with mouse from the item menu: M3F

Select with mouse from the item menu: M4F

Select with mouse from the item menu: M5F

Select with mouse from the item menu: total

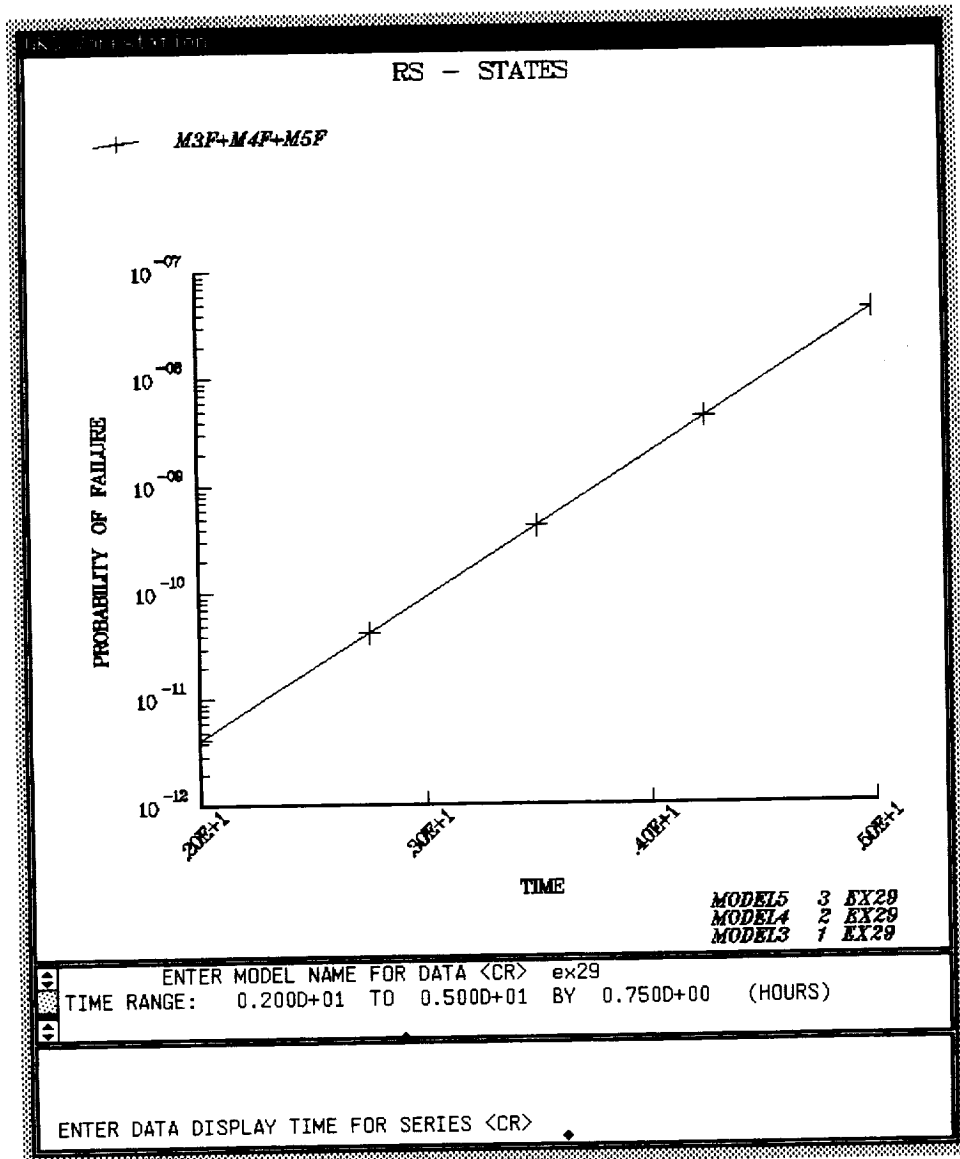
See next page for results.



Select with mouse from the submenu: EXIT

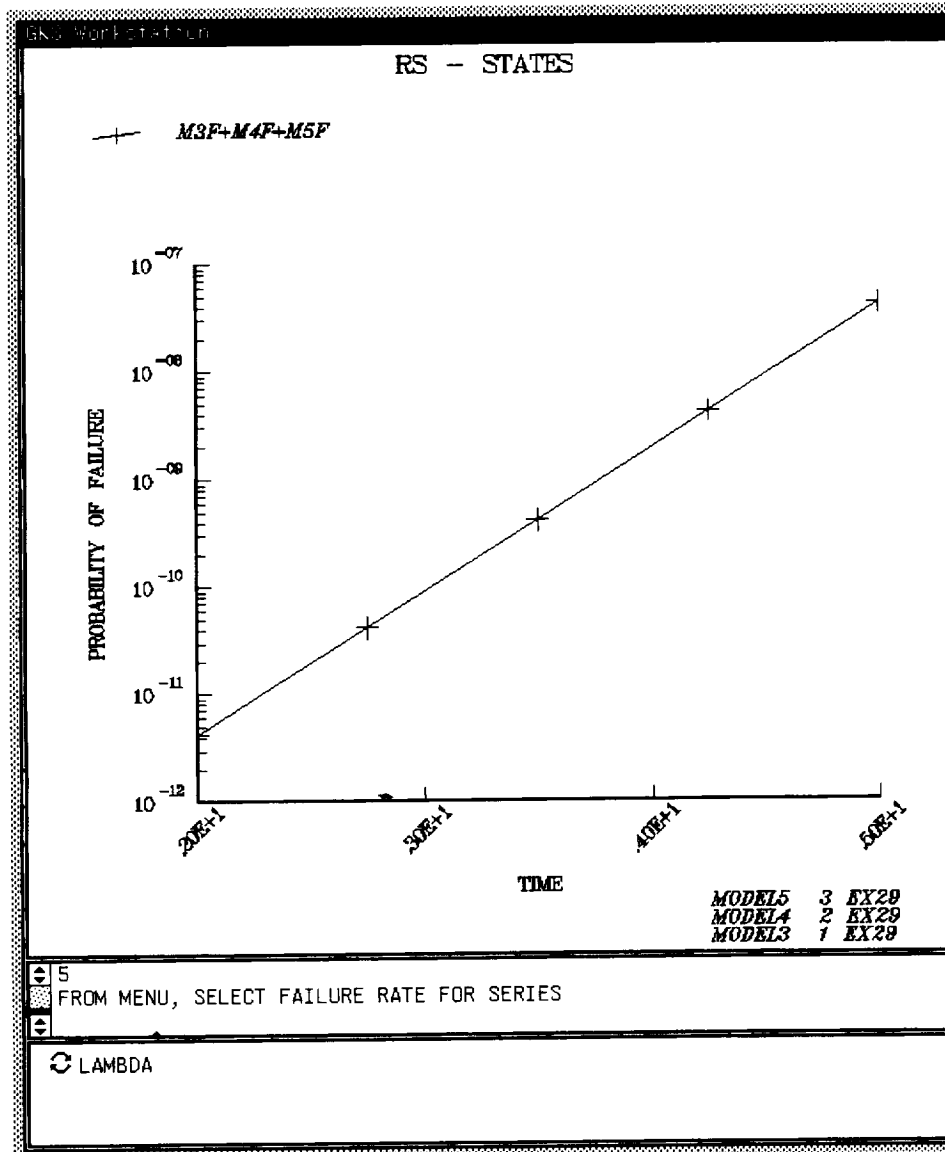
Select with mouse from the main menu: FAILURE SERIES

Enter with keyboard the model name: ex29



Enter with keyboard the display time: 4.25

See next page for results.

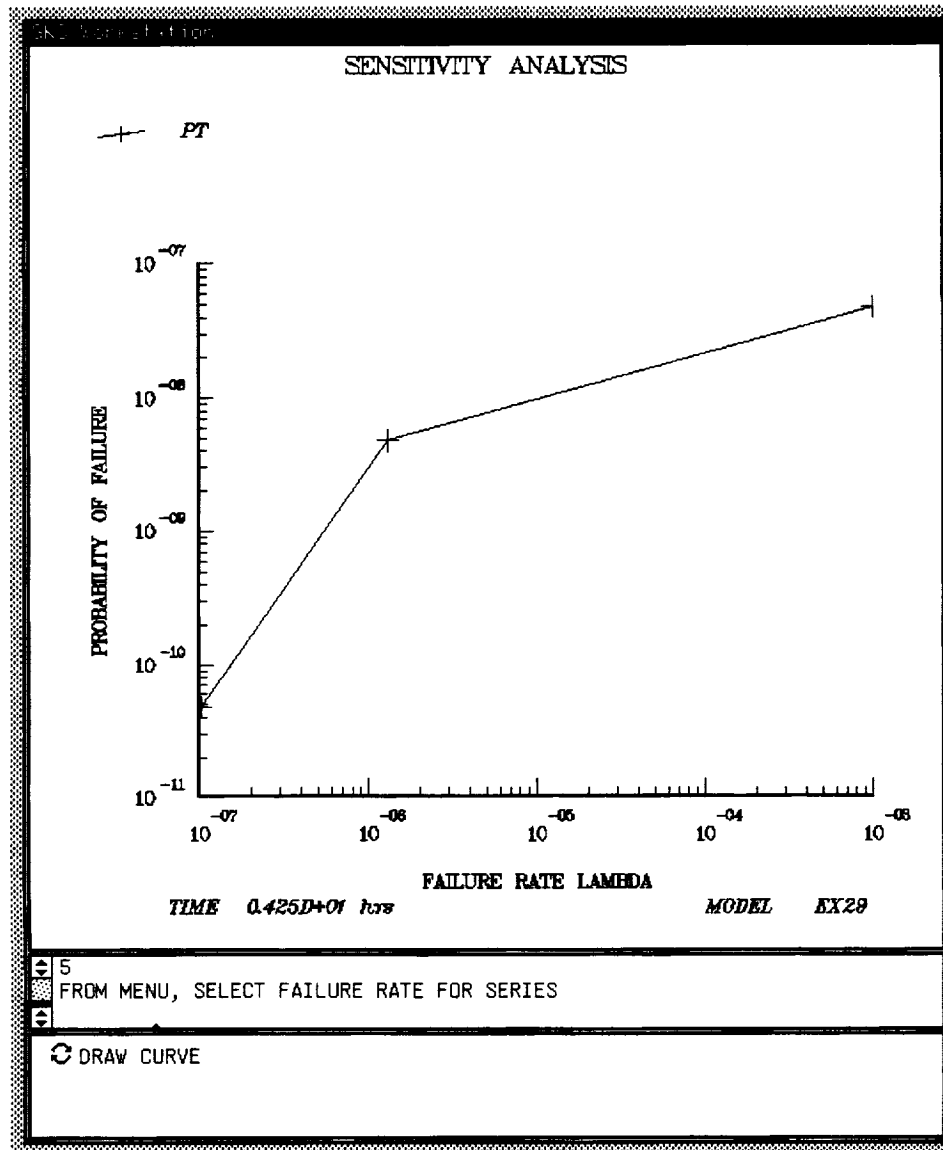


Select with mouse from the item menu: LAMBDA

Select with mouse from the submenu: DRAW CURVE

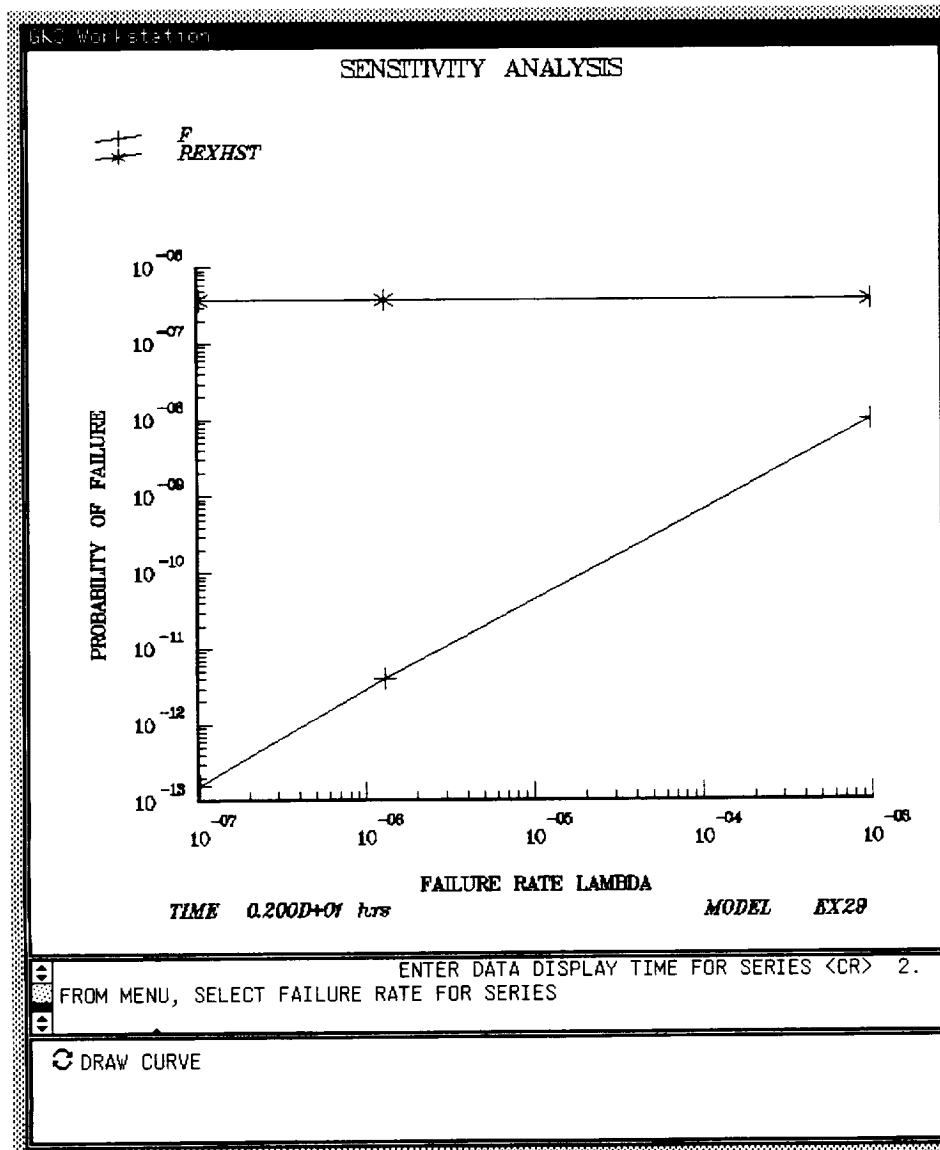
Select with mouse from the item menu: PT

See next page for results.



Select with mouse from the submenu:	EXIT
Select with mouse from the main menu:	FAILURE SERIES
Enter with keyboard the model name:	ex29
Enter with keyboard the display time:	2.
Select with mouse from the item menu:	LAMBDA
Select with mouse from the submenu:	DRAW CURVE
Select with mouse from the item menu:	F
Select with mouse from the submenu:	DRAW CURVE
Select with mouse from the item menu:	REXHST

See next page for results.



Select with mouse from the submenu: EXIT

Select with mouse from the main menu: QUIT

Enter with keyboard the query: Y

Save internal data files?: n or <CR>

The program should have terminated completing the session. The user is encouraged to execute HARPO again to experiment with the program's features.

Appendix B

Error Messages

ERROR: DATA FILE COULD NOT BE OPENED

A FORTRAN error occurred when the program attempted to open the PPT file for the user requested state. An error of this type may require program modification and should be reported to the software distributors.

ERROR: DATA UNAVAILABLE FOR SELECTED ACTION

The user attempted an action requiring a specific type of data, such as a BD state, which does not exist for the model selected. Review text of the HARP RS* data file(s) of the selected model for the discrepancy or select different action or model.

ERROR: EXCEEDED MAXIMUM NUMBER OF MODELS

The user attempted to name too many models for activation. Use the main menu option DACTV/ACTV_MDL to replace an active model. Request a limits upgrade from the software distributors if this limit restricts the desired analysis.

ERROR: EXCEEDED MAXIMUM NUMBER OF STATES

While parsing the RS states of the activated models, the program reached the size limit of the arrays for the RS state names. The PT and BD states are limited by the number of models that can be loaded. Create space for the desired model by using the main menu option DACTV/ACTV_MDL to deactivate model(s). Request a limits upgrade from the software distributors if this limit restricts the desired analysis.

ERROR: FAILURE RATE UNAVAILABLE FOR ALL MODELS

The program encountered the condition where all models in the user-selected series do not contain all the same symbolic failure rate names. The user has selected one of the failure rates that does not exist for all models being used for the series analysis. Review the currently activated models and text of the HARP RS* data file(s) for the discrepancy. Use the main menu option DACTV/ACTV_MDL to deactivate any undesired model(s).

ERROR: INCONSISTENT NUMBER OF STATE POINTS

The program encountered the condition where all states that the user selected for summation do not have the same number of data points. At least one PPT file for the selected states differs in the number of data points contained by the others tested. Review text of the HARP RS* data file(s) of the currently active model(s) for the discrepancy or select a new series of states for summation.

ERROR: INSUFFICIENT NUMBER OF STATE POINTS

The program encountered the condition where only one data point exists for plotting. The user either selected a state whose PPT file contains only one time interval or a series model name with only one version available. Additional time steps must be available for the desired state. Create new HARP RS* data file or activate additional versions of the model named for the series analysis if required.

- ERROR: INSUFFICIENT STORAGE FOR DATA ARRAY
While reading the PPT file for the user-selected state, the program reached the size limit of the X- and Y-arrays for the state data, that is, too many time steps. Request a limits upgrade from the software distributors if this limit restricts the desired analysis.
- ERROR: INVALID ENTRY FOR DEFINING MODEL
The user entered only a carriage return in response to the model specification prompt(s). Properly enter a new model specification by using the main menu choice ADDNL . MODEL.
- ERROR: INVALID ENTRY FOR TIME
The user entered a time for the series analysis for which data does not exist. The data may have been incorrectly derived or entered in the wrong format. Review the value entered or text of the HARP RS* data file(s) of the currently activated models' for the discrepancy.
- ERROR: INVALID VALUES FOR DEFINING WINDOW
The program encountered the condition where the minimum and maximum values for the X- or Y-data of a state are equal. A window cannot be defined with a range of zero. Review text of the HARP RS* data file(s); create new HARP RS* data file(s) if required.
- ERROR: MAXIMUM NUMBER OF CURVES DISPLAYED
The user requested a curve to be drawn when the maximum number of curves on a graph was already displayed. Create space for new curve by removing a displayed curve with the submenu choice DELETE CURVE.
- ERROR: MODELS UNAVAILABLE FOR SELECTED NAME
The user specified a model name for the series analysis that does not match any of the models loaded. Use main menu option DACTV/ACTV _MDL to review active models, or use the ADDNL . MODEL choice to activate models for analysis.
- ERROR: NO CURVES ARE DISPLAYED
The user requested a curve be deleted when no curves were displayed on the graph. Continue with processing.
- ERROR: PREMATURE END OF FILE OCCURRED
The program encountered the condition where no values or an unexpected number of values were encountered while reading a data file. Review text of the HARP RS* data file(s) to confirm data exist. If no problem is found, report the occurrence to the software distributors; an error of this type may require program modification.
- ERROR: PROCESSED MAXIMUM NUMBER OF MODELS
While executing a single HARPO session, the user attempted to load a model exceeding the limit on the number of activated and deactivated models per session (limit on number of digits available for model naming conventions). Terminate the program ending current analysis session, then begin a new session.
- ERROR: STATE UNAVAILABLE FOR ALL MODELS
The program encountered the condition where all models in the user-selected series do not contain all the same states. The user has selected one of the states that does not exist for all models being used for the series analysis. Review the currently activated models and text of their HARP RS* data file(s) for the discrepancy. Use the main menu option DACTV/ACTV _MDL to deactivate any undesired model(s).

ERROR: TIME UNAVAILABLE FOR DATA OF ALL MODELS

The program encountered the condition where all models in the user-selected series do not contain all the same time intervals. The user has selected one of the time intervals that does not exist for all models being used for the series analysis. Review the currently activated models and text of their HARP RS* data file(s) for the discrepancy. Use the main menu option DACTV/ACTV_MDL to deactivate any undesired model(s).

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5. Geist, Robert: Extended Behavioral Decomposition for Estimating Ultrahigh Reliability. *IEEE Trans. Reliab.*, vol. 90, Apr. 1991, pp. 22–28.
6. McKay, Lucia: *GKS Primer*. Nova Graphics International Corp., 1984.

Appendix C

Glossary

active model	An active model is the HARP RS* data file that has been loaded, parsed, and made available for analysis. In other words, PPT files have been generated.
BD	The BD (bounds data) is the value at each time interval for the simple lower (BDLO) and upper (BDUP) bounds on unreliability. The BD is used for the failure probability bounds graph.
BST	The BST data are best-case data values obtained by selecting the truncation option when running <i>harpeng</i> .
curve	A curve is a line plot of X-Y data for a state.
FEHM	FEHM is the fault/error-handling model.
FR	The FR (failure rate) data are values for symbolic failure rates and the exit probabilities of the FEHM's. The FR is used for the sensitivity analysis graph.
graph	A graph is a set of one or more curves used to compare and analyze state data.
item menu	An item menu is a list built by the program of available data items, such as models activated for analysis, states for a type of data, or states whose data have been displayed as curves.
model name	The model name consists of the characters of a HARP RS* data file name immediately preceding the characters .RS.
parse	Parse is the process of the program that separates and compacts all data for each of the states in a HARP RS* data file then writes it to PPT files.
PC	The permanent coverage (PC) data values are defined by user selected FEHM's.
PPT	The PPT (plot point) file contains only the raw data required for a curve as parsed from a HARP RS* data file. Each line of the file contains a single pair of values.
PT	The PT (plot data) is the value at each time interval for unreliability. The PT is used for the unreliability and sensitivity analysis graphs.
REXHST	REXHST are data values computed by <i>harpeng</i> that predict system failure resulting from the exhaustion of redundant components.
RS	The RS (results data) is the value at each time interval for any state probability available. The RS is used for the state and sensitivity analysis graphs.
RS*	The RS* is a file containing the results data.

series	A series is a set of HARP RS* data files with differing version numbers and the same name. The series is created by rerunning the HARP engine during a single session. The value of the same symbolic failure rate in each version is expected to vary.
SF	The single-point failure (SF) data values are defined by user selected FEHM's.
state	A state is a type of data from a HARP RS* data file, such as PT, RS, or BD.
submenu	A submenu is a menu that is displayed as a result of selecting a choice from the main menu.
TR	Transient restoration (TR) data are values obtained from a user-selected FEHM.
truncated model	A truncated model results when a HARP engine run obtains bounds for the model results after a specified number of faults have occurred. This type of model has a set of values representing the best case and worst case at each time interval of the PT state and all RS states.
version of model	The version of the model is the value of the digit in a HARP RS* data file name immediately following the characters .RS. This value signifies the <i>n</i> th rerun of the HARP engine during a single session.
WST	WST data are worst-case data values obtained by selecting the truncation option when running <i>harpeng</i> .

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13. ABSTRACT (Maximum 200 words) The Hybrid Automated Reliability Predictor (HARP) integrated Reliability (HiRel) tool system for reliability/availability prediction offers a toolbox of integrated reliability/availability programs that can be used to customize the user's application in a workstation or nonworkstation environment. HiRel consists of interactive graphical input/output programs and four reliability/availability modeling engines that provide analytical and simulative solutions to a wide host of highly reliable fault-tolerant system architectures and is also applicable to electronic systems in general. The tool system was designed at the outset to be compatible with most computing platforms and operating systems and some programs have been beta tested within the aerospace community for over 8 years. This document is a user's guide for the HiRel graphical postprocessor program HARPO (HARP Output). HARPO reads ASCII files generated by HARP. It provides an interactive plotting capability that can be used to display alternate model data for trade-off analyses. File data can also be imported to other commercial software programs.				
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